A METHODOLOGY FOR ESTABLISHING MAXIMUM AIRCRAFT COMBAT TURN RATES

THESIS

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Presented to the Faculty of the Graduate School of

Logistics and Acquisition Management of the

Air Force Institute of Technology

Air Education and Training Command

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Logistics Management

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September 1994

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Preface

The purpose of this study was to develop a methodology for establishing maximum aircraft combat turn rates for use in the Sustainability Assessment Module (SAM). The SAM assessments influence a unit's Capability Level as reported in the Status of Resources and Training System. The maximum turn rate is the maximum number of sorties an aircraft can fly in a 24-hour period. The current maximum turn rates are questionable because of the lack of a valid methodology.

Relationships between sortie generation factors were developed to produce a methodology for establishing maximum turn rates. A comparison between SAM outputs which utilize current maximum turn rates and maximum turn rates calculated by the proposed methodology suggests that the methodology proposed in this thesis can produce more accurate maximum turn rates.

We are deeply indebted to our thesis advisors, Lt Col Phillip Miller and Major Marsha Kwolek, for their guidance and encouragement throughout this thesis. We wish to thank Norman Hass and John Frabotta for supplying data and lending their experience to our research. Finally, we thank our wives, Margaret and Michelle, for their support and understanding through the long nights and frustrating days along the way.

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Abstract

The Air Force relies on the Status of Reports and Training System (SORTS) as an indicator of unit readiness. Unit Capability Levels (C-Levels) reported in SORTS are determined through measurements of on-hand resources and computer estimates of unit capabilities. Aircraft maximum turn rate, defined as the maximum number of sorties an aircraft can fly in a 24-hour period, is an input parameter to the assessment model. The methods used today produce maximum turn rates with unverifiable accuracy. Unit capabilities required to generate aircraft sorties are documented and their relationship to maximum turn rate established in this study. A unit capabilities based methodology for determining maximum turn rates is then proposed in this study. Results of the assessment model utilizing current maximum turn rates are compared to model results utilizing maximum turn rates calculated through the proposed methodology.

A METHODOLOGY FOR ESTABLISHING MAXIMUM AIRCRAFT COMBAT TURN RATES

I. Introduction

Background

The United States Air Force (USAF) war planning process originates within the Department of Defense (DOD) Planning, Programming, and Budgeting System (PPBS) and the Joint Strategic Planning System (JSPS). The objective of the PPBS is to provide combatant commanders the optimal combination of manpower, equipment, and support attainable within fiscal constraints. The JSPS provides the formal process for an analysis of United States national security objectives, threat evaluations, and assessments of strategy, programs, and budgets (Armed Forces Staff College, 1993:5-4). The PPBS and JSPS systems furnish the services and combatant commanders with warfighting requirements and capabilities (Armed Forces Staff College, 1993:5-5).

Once resources have been allocated in the formal PPBS and JSPS processes, the Joint Strategic Capabilities Plan (JSCP) is published. The JSCP gives strategic planning guidance for developing conceptual and operational war plans to each Unified Commander-In-Chief (CINC) and the Service Chiefs. The JSCP provides planning guidance, objectives, tasks, and major force apportionment for wartime planning (Armed Forces Staff College, 1993: 5-17).

War planning in the USAF is accomplished with the aid of automated systems. The primary system employed by the USAF is the World Wide Military Command and Control System (WWMCCS). The WWMCCS is a composition of communication and information systems which provide the means for operational direction and technical administrative support involved in the command and control of U.S. military forces (Armed Forces Staff College, 1993:5-25).

One subsystem of the WWMCCS is a data collection and processing network. Embedded within this network is a hierarchy of automated data processing (ADP) capabilities, databases, and applications software (Armed Forces Staff College, 1993:5-26). The USAF has incorporated the Weapon System Management Information System (WSMIS) into the WWMCCS at this ADP level.

WSMIS predicts wartime USAF capabilities through analyses of current logistics status projected into Conceptual and Operational Plans. WSMIS accomplishes this analysis through two primary functions: assessment of an aircraft weapon system's readiness and sustainability and the identification of resources that limit the weapon system's achievement of required readiness and/or sustainability levels (Dynamics Research Corporation, 1990:1).

WSMIS is comprised of seven assessment modules. Collectively the modules assess aircraft availability,

projected combat capability with available resources, spares requirements, repair funds, quarterly repair workloads, and weapon system goals and priorities (Dynamics Research Corporation, 1990:1). WSMIS integrates the information generated by the modules to provide a comprehensive view of warfighting capability and combat support effectiveness.

The Sustainability Assessment Module (SAM) is one of the seven modules found within WSMIS. The SAM provides:

> the Air Force Material Command (AFMC) System Program Directors (SPDs), Product Managers, Major Commands (MAJCOMs), and Air Staff with the analytical capability to determine resources required for wartime tasking, and to thus accomplish their day-to-day operational assignments. (Department of the Air Force, 1992a:2-1)

Additionally, the SAM is utilized as the "Air Force's tool for the Major Commands (MAJCOMs) to determine their Status of Resources and Training System (SORTS) Capability Level (C-Level) ratings" (Dynamics Research Corporation, 1990:3).

The computational mechanism within the SAM is the Dynamic Multi-Echelon Technique for Recoverable Item Control (Dyna-METRIC) algorithm (Department of the Air Force, 1992a:2-1). The Dyna-METRIC Version 4.6 algorithm "assesses the effects of wartime dynamics on repair constraints and provides operational performance measures,

problem detection, and spares requirements" (Isaacson & Boren, 1993: iii). The Dyna-METRIC model compiles a variety of operations and logistics parameters which represent an expected campaign environment and produces projected operations performance, potential line replaceable unit problems, and part pipeline status (Isaacson & Boren, 1993:12).

The Dyna-METRIC model has been adopted as a standard assessment tool within the USAF. It provides logisticians with the capability to assess how repair processes, stock levels, transportation processes, operations, and wartime plans interact to affect combat capability (Isaacson, and others, 1988:1).

The accuracy of the output reports created by the Dyna-METRIC model is dependent upon legitimate input data. This input data represents the warfighting scenario which is receiving an assessment. One of the required scenario inputs to the Dyna-METRIC model is the maximum aircraft combat turn rate. The maximum aircraft combat turn rate input is defined as "the maximum number of sorties an available aircraft can fly per day at each base" (Isaacson & Boren, 1993:11).

Maximum aircraft combat turn rates presently used in the SAM assessments have been established by each Major Command (MAJCOM). Different MAJCOMs flying the same Mission Design Series aircraft are using different maximum aircraft combat

turn rates in the current SAM assessments (Hass & Frabotta, 1994). This random selection of maximum aircraft combat turn rates has resulted in Air Staff concerns that the SAM assessments are inaccurate (Peterson, 1993).

The SAM assesses the weapon system's readiness and sustainability throughout a specified duration, usually in 30 day increments. The maximum aircraft combat turn rate input is defined for each day of the scenario assessment (Isaacson and others, 1988:198). The MAJCOMs currently determine and provide the daily maximum aircraft combat turn rate input. In certain assessments the maximum aircraft combat turn rates are held constant for the duration of the SAM run, while in others the maximum aircraft combat turn rate is varied throughout the scenario (Hass & Frabotta, 1994). The inconsistent selection and application of maximum aircraft combat turn rates in the SAM assessments discredits the reliability of projected support requirements and warfighting capability estimates produced by the SAM.

Specific Problem

There is currently no validated methodology for establishing maximum aircraft combat turn rates for war planning (Peterson, 1993). This deficiency has resulted in potential inaccurate assessments of our ability to sustain wartime operations (Burleson, 1993).

Research Objective

The objective of this research is to propose a methodology for establishing Air Force maximum aircraft combat turn rates. The maximum aircraft combat turn rates produced by the methodology are intended for utilization within the Dyna-METRIC model for the purpose of generating WSMIS/SAM capability assessments. The methodology will strive to realistically represent the environment in which military operations are conducted. The consideration of operations, logistics, and manpower factors is essential in the development of the methodology.

Research Questions

The following questions must be answered to attain our primary research objective:

1. What is the purpose of the maximum aircraft combat turn rate input to the Dyna-METRIC model?

2. What is the relationship between maximum aircraft combat turn rates and unit capability assessments?

3. Does the maximum aircraft combat turn rate significantly influence unit capability assessments?

4. What operational characteristics that are not specific inputs to the capability assessment process affect the determination of maximum aircraft combat turn rates?

5. What methodology best establishes a valid and accurate maximum aircraft combat turn rate?

Scope

This research will be limited to defining a methodology for establishing maximum aircraft combat turn rates. The maximum aircraft combat turn rates produced by this methodology are to be used as inputs to the Dyna-METRIC model within the SAM. Outside of this application, maximum aircraft combat turn rates may take on other definitions. Since the SAM is the accepted model for estimating Air Force Wing, Major Command, and Theater level warfighting capabilities, the authors believe that this research should be devoted to solving the problem of improving the accuracy of the capability assessments produced by the SAM.

The Dyna-METRIC model requires a variety of inputs in order to represent a wartime scenario. The intent of this research is not to replicate the process of establishing Dyna-METRIC model scenarios. Rather, we are interested in analyzing the effects caused by the maximum aircraft combat turn rate input. The research will focus on developing a methodology which provides realistic and accurate maximum aircraft combat turn rates.

Chapter Summary

This chapter presented the basic Air Force operational and planning problems associated with a lack of an accepted methodology for establishing maximum aircraft combat turn rates. The chapter introduced the impact of maximum aircraft combat turn rates on war planning and reported readiness status of Air Force units. The lack of a standardized methodology for estimating and applying maximum aircraft combat turn rates was discussed.

Thesis Overview

Chapter II provides a detailed background discussion of the literature concerning maximum aircraft combat turn rate utilization, characteristics, and methodologies. Chapter III will readdress the research questions presented in Chapter I; justify the selection of the research methodology; provide a comprehensive description of the proposed maximum aircraft combat turn rate methodology; and explain the experimental design and statistical analysis associated with the proposed methodology. Chapter IV focuses on the actual experimental testing of the proposed methodology. An analysis of the application of the proposed methodology concludes this chapter. Chapter V contains the conclusions drawn from the research. The significance of a standardized maximum aircraft combat turn rate methodology, the justification of the proposed maximum aircraft combat

turn rate methodology, recommendations associated with the proposed methodology, and suggestions for further research are also provided in Chapter V.

II. Literature Review

Introduction

Basic aerospace doctrine of the USAF defines a military operation as the process of conducting combat, which includes the movement, supply, attack, defense, and maneuvers needed to attain the objectives of any battle or campaign (Department of the Air Force, 1992b:295). The USAF conducts and supports military operations through the application of airpower. An attribute of airpower is flexibility, which USAF doctrine describes as "the ability to adjust forces or any proportion of forces from one objective or task to another as the need arises" (Department of the Air Force, 1992b:283). While flexibility enhances operations, limitations exist which constrain operations.

The limitations of airpower can be classified into two basic categories, manpower and aircraft. Manpower is required to operate, maintain, and manage aircraft resources. Manpower limitations include the number of available aircrews and ground support personnel, personnel skill levels, and aircrew duty day length, rest requirements, and preparation time (Stiles, 1993:27). The aircraft is a weapon system designed to conduct operations in support of military objectives. Aircraft limitations include the number of aircraft available to a unit; the performance characteristics of speed, range, and maneuverability; and the logistical aspects of reliability,

maintainability, and sustainability. The manpower and aircraft variables constitute the primary influences that ultimately determine the limits of airpower (Stiles, 1993:27).

The maximum number of sorties an aircraft can physically perform in a 24-hour period is a specific limitation on USAF operations. This constraint was defined previously as the maximum aircraft combat turn rate. The abbreviated term, maximum turn rate, will be applied throughout the remainder of this thesis. The maximum turn rate is a limitation which is dependent on the wartime scenario, manpower, and aircraft variables. Specific relationships between these baseline variables establish the maximum turn rate.

The maximum turn rate is a measurement of maximum sortie production. However, theater and unit level commanders do not directly utilize maximum turn rates in readiness assessments and mission planning activities (Burleson, 1993). Instead, commanders formulate operational decisions based on the readiness attributes that are summarized in the Status of Resources and Training System (SORTS) (Moore and others, 1991:10). The combat readiness information reported in SORTS is influenced by maximum turn rates. Therefore, a detailed explanation of how the maximum turn rate is integrated into SORTS will establish the indirect, yet significant relationship between maximum turn rates and USAF assessments of warfighting capabilities.

The purpose of this literature review is to introduce the concept of maximum turn rate, describe the automated environment in which a maximum turn rate is utilized, explain the significance of maximum turn rates with respect to unit capability assessments, analyze methods and policies which establish maximum turn rates, and present current methodologies for estimating maximum turn rates.

Maximum Turn Rates

An aircraft maximum turn rate is simply defined as the maximum number of sorties an available aircraft can fly per day at each base (Isaacson & Boren, 1993:11). The specific length of a day is 24 hours and the term "base" is analogous to any location in which aircraft operations are conducted. The maximum turn rate sets an upper limit on the number of sorties a single aircraft can perform each day. While operational commanders have the flexibility to adjust sortie schedules, accelerate sortie rates, and compensate for lost sorties, the achievability of a unit's overall flying program is ultimately limited by the aircraft maximum turn rate (Isaacson & Boren, 1993:11).

The concept of maximum turn rate is relatively easy to understand, yet the formulation of a methodology to determine accurate maximum turn rates has eluded operations and logistics planners (Peterson, 1993). Before attempting to derive a methodology for establishing maximum turn rates,

it is important to understand the significance of maximum turn rates. This significance will be established through descriptions of: the hierarchy of automated data systems in which maximum turn rates are utilized; the relevant assessments created by the data systems; the source of unit taskings; and the capability level measurements influenced by the maximum turn rates. This system is called the Maximum Turn Influence Chain and is pictured in Figure 2.1.

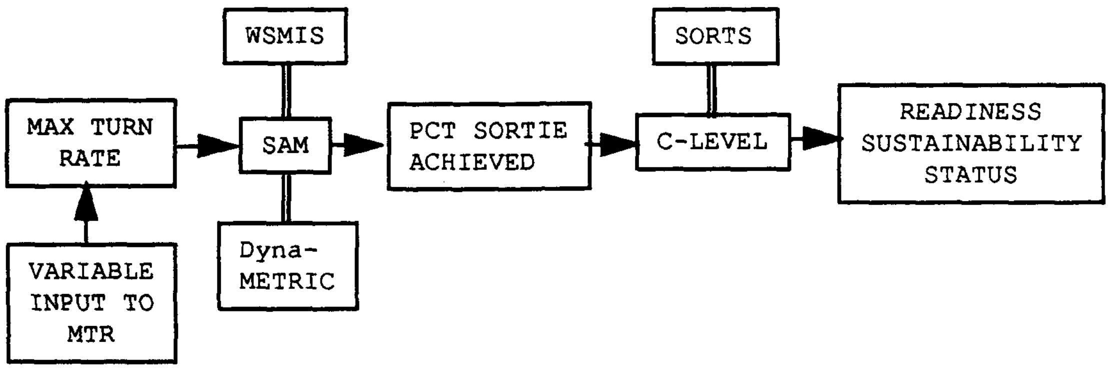


Figure 2.1. Maximum Turn Rate Influence Chain

Weapon System Management Information System (WSMIS)

WSMIS was developed as an analysis tool to rigorously assess the overall capability of a weapon system's abilities to perform wartime taskings. WSMIS is an automated data management system that performs three primary functions (Dynamics Research Corporation, 1990:1):

1. Assessment of each aircraft weapon system's readiness and sustainability.

2. Identification of resources that limit the weapon system's achievement of specified readiness and/or sustainability objectives.

3. Development and monitoring of plans to reduce the impact of resource limitations upon the weapon system's combat capability.

Table 2.1. Summary of WSMIS Modules

MODULE	PURPOSE
Sustainability Assessment Module (SAM)	Predicts the combat capability of a given weapon system with available resources.
Readiness Assessment Module (RAM)	Assesses combat readiness and availability of aircraft to meet designated wartime mission.
Get-Well Assessment Module (GWAM)	Provides information and analysis tools to resolve logistics problems identified by SAM and RAM.
Requirements/Execution Availability Logistics Module (REALM)	Computes spares requirements and identifies priorities for budget allocation.
Distribution and Repair In Variable Environments (DRIVE)	Allocates repair funds, plans quarterly repair workloads, and supports depot repair execution.
Automated Weapon System Master Plan (AWSMP)	Integrates weapon system planning and provides on-line display of weapon system goals and priorities.
Modifications Management System (MMS)	Provides information on weapon system modification requirements.

WSMIS consists of seven integrated modules that perform assessment operations. The information within WSMIS is

collected from a variety of Air Force data systems for entry into an integrated data base. The seven modules access this data and generate their capability and sustainment projections. Table 2.1 summarizes the WSMIS modules (Dynamics Research Corporation, 1990:1).

The SAM is the automated data module within WSMIS which directly utilizes maximum turn rates. The maximum turn rate is an input to the SAM which defines a realistic operational constraint on a unit's combat capability.

Sustainability Assessment Module (SAM)

The primary purposes of the SAM are to provide war plan weapon system logistics assessments and projections of combat sustainability at the unit, wing, and theater levels (Department of the Air Force, 1992a:2-1). A description of the SAM is provided by the WSMIS/SAM *End Users Manual*:

> the SAM is an automated logistics decision support tool which predicts combat capabilities and limitations of aircraft using OPLANS, logistics resources data, and logistics performance data as inputs. (Department of the Air Force, 1992a:1-18)

The WSMIS/SAM operates on the Headquarters Air Force Material Command's Worldwide Military Command and Control System (WWMCCS) and WSMIS computer systems at Wright-Patterson AFB, Ohio. The SAM assessments of a unit's projected 30-day cumulative sortie and available aircraft

percentages are performed on a weekly basis (Department of the Air Force, 1992a:4-2).

The inputs to the SAM are described in the *End Users Manual*. These inputs include:

> A wartime Flying Hour Program (FHP) stored within the OPLAN master file (WMP planned and notional combat tasking); item descriptive data such as demand rates and repair cycle times of items in the contingency kit; and the on hand asset level positions. (Department of the Air Force, 1992a:2-2)

At the heart of the SAM information processing system is the Dynamic Multi-Echelon Technique for Recoverable Item Control (Dyna-METRIC) model (Department of the Air Force, 1992a:2-1). The Dyna-METRIC model is the specific computational mechanism within the SAM which requires a maximum turn rate as an essential input.

Dyna-METRIC

Scope. The Dyna-METRIC model represents a realistic and dynamic wartime environment. An analyst can develop a scenario by specifying the number and types of aircraft, at single or multiple bases, in one or more theaters of operation, and over a period of time which may range from several days to several years (Isaacson and others, 1988:4). Designed as an analysis tool for logisticians, the Dyna-METRIC model is an analytic model that uses mathematical

equations to forecast how logistics support processes would affect flying units' capability in the specified dynamic wartime environment (Pyles, 1984:8).

The theoretical development of the dynamic queuing equations that form the Dyna-METRIC model's algorithms is presented in Hillestad and Carrillo (1980) (Hillestad, 1982:5). A detailed review of these equations is beyond the scope of this report. In general, the dynamic wartime environment is modeled by combining time-dependent component removals due to operational demands with time-dependent logistics functions (repair, resupply, and transportation times) to estimate expected pipeline quantities as a function of time (Isaacson and others, 1988:7).

The primary logistics support process for which the Dyna-METRIC model provides analysis is component repair and replenishment. The Dyna-METRIC model simulates the logistics support process "as a network of pipelines through which components flow as they are repaired or replaced" (Isaacson and others, 1988:6). The Dyna-METRIC model computes the anticipated number of components at various segments of this pipeline network.

The Dyna-METRIC model is based on two assumptions that define the relationship between the wartime environment in which operations are conducted and the logistics support network which provides operational sustainability. These assumptions are that component and parts removal and

replacement are proportional to flying hours and that mean part demand rates and variation about these means are known (Isaacson and others, 1988:v).

Input Parameters. The Dyna-METRIC model represents the time-dependent processes associated with the transition from a steady-state peacetime to a dynamic wartime environment. The initial inputs to the model define both the steady-state peacetime activities and the wartime scenario of interest (Isaacson and others, 1988:18). There are seven record groups which detail the Dyna-METRIC model input data, one of which is the maximum sortie rate (Isaacson and others, 1988:19).

Isaacson defines maximum sortie rates as "the maximum number of sorties per day for each aircraft at a base" (Isaacson and others, 1988:21). The maximum sortie rate is another term for maximum turn rate. Note that these terms share the same definition and can be used interchangeably. Throughout this thesis the term "maximum turn rate" shall be used.

The inputs to the Dyna-METRIC model are selected at the discretion of the analyst and provide the flexibility to model an unlimited number of hypothetical wartime scenarios. After defining the desired scenario, the analyst selects the appropriate Dyna-METRIC model assessment capability.

Capabilities. The Dyna-METRIC model provides the analyst three primary assessment capabilities (Isaacson and

others, 1988:8). The capability of interest is the performance measures assessment. This assessment provides component-oriented logistics statistics and combat-oriented capability.

The combat-oriented capability measures produced by the Dyna-METRIC model include aircraft availability and sortie generation capability (Isaacson and others, 1988:8). The Dyna-METRIC model also estimates the expected number of sorties a base can fly for each day of the scenario with respect to the flying program specified in the input data. Note that a limitation placed on the flying program is the maximum turn rate.

The Dyna-METRIC model will repeatedly fly fully mission capable (FMC) aircraft until all requested sorties have been accomplished if a maximum turn rate is not included as an input to the prospective flying program (Peterson, 1993). The flying program will have a one hundred percent sortie achievement rate as long as the Dyna-METRIC model recognizes even a single available FMC aircraft (Niklas, 1994). The inclusion of the maximum turn rate guarantees that a single aircraft cannot perform more sorties than physically feasible in a 24-hour period.

Output Reports. The Dyna-METRIC model's output report of interest is the Performance Report, which summarizes the performance measures assessments. The Performance Report

provides combat-oriented capability measures of the following (Isaacson and others, 1988:27):

1. Probability that a specified percentage of aircraft are Not Fully Mission Capable (NFMC) at the end of a day.

2. Probability of achieving the current day's sortie rate based upon the aircraft status of the previous day.

3. The number of FMC aircraft at the end of the day based upon the specified confidence level.

4. The expected number of NFMC aircraft.

5. The expected number of NFMC aircraft as a percentage of the total aircraft assigned to a base.

6. The expected number of sorties achievable based upon the expected status at the end of the current day.

7. The expected number of sorties per FMC aircraft.

The maximum turn rate directly affects the determination of items 2, 6, and 7 above, whereas the number of FMC and NFMC aircraft is calculated independently of the maximum turn rate (Niklas, 1994). The variation of the maximum turn rate with respect to these output measures shall be discussed in greater detail later in this thesis.

The purpose of this extensive Dyna-METRIC model discussion has been to establish the automated environment which utilizes the maximum turn rate input. The maximum turn rate is an operational constraint incorporated into the Dyna-METRIC model to enhance the realism of a scenario.

While this contribution may appear to be minimal, the output products generated by the Dyna-METRIC model are integrated into the SAM to produce measures of projected operational capability and sustainability. These capability and sustainability measures provide critical assessments of the capabilities of the USAF to sustain wartime operations (Burleson, 1993).

SAM Output Products

The SAM produces a variety of output reports, one of which is the capability assessment report. This report provides capability assessment summaries of projected sorties and available aircraft for specific units and theaters of operation (Department of the Air Force, 1992a:A1-12). The SAM combines scenario information, aircraft parts usage rates, and asset level data to generate the capability assessment report (Department of the Air Force, 1992a:2-6).

The summary statistics section of the report lists the percentage of daily FMC aircraft, average number of sorties flown on each day, and the daily percentage of sorties achieved (Department of the Air Force, 1992a:A1-12). The daily percentage of sorties achieved is proportional to the maximum turn rate. As the maximum turn rate increases or decreases, the respective capability to achieve sorties increases or decreases (Niklas, 1994).

The SAM output products are transmitted through the Worldwide Military Command and Control System (WWMCCS) Intercomputer Network (WIN). The WIN system,

> establishes a set of command and control capabilities supporting the National Command Authorities, the Joint Staff, and major field commanders down to the service component command. (Department of the Air Force, 1992a:1-19)

The accuracy of the SAM assessments is critical in that the highest levels of the military command structure rely on the SAM information for force employment, combat strategy and unit tasking decisions.

The SAM outputs provide vital assessments of warfighting capability at the unit level. The WSMIS/SAM *End Users Manual* states:

> SAM output is reported through the Status of Resources and Training System (SORTS). SORTS sustainability measures of merit consist of the SAM Day 30 available aircraft and/or cumulative sorties/missions achieved percentages. The SAM available aircraft and sortie percentages are used to determine the Capability Level (C-Level) of Air Force units with wartime roles. (Department of the Air Force, 1992a:2-2)

The percentage of sorties achieved, which is dependent on the maximum turn rate, is a significant factor in the determination of a unit's warfighting capabilities. This capability is reported in the Status of Resources and Training System (SORTS).

Status of Resources and Training System (SORTS)

SORTS is an automated data system which provides National Command Authorities, Joint Chiefs of Staff, and Unified and Specified commanders with authoritative identification, location, and resource information for crisis action. SORTS is also used throughout the chain of command to measure daily resource status of operational forces (Department of the Air Force, 1992c:8).

The SORTS reporting system updates computer databases and provides current information on unit personnel strength, resources capabilities, equipment condition, and training status. These measures of capability represent the four categories of Capability Levels (C-Levels) of a unit (Department of the Air Force, 1992c:7). Therefore, the accuracy of the information within SORTS is dependent upon the inputs into C-Level calculations.

It is worthwhile to introduce the source of a unit's taskings before proceeding with a discussion of C-Levels. The Designed Operational Capability (DOC) Statement provides this information.

Designed Operational Capability (DOC) Statement

The DOC Statement is the fundamental source for unit taskings. War plan tasked active, Air Force Reserve, and Air National Guard units have been designed and organized to

perform combat or combat support missions. The specific wartime missions, taskings, and requirements contained in approved operations plans, functional manager taskings, and other directives are summarized in the unit's DOC Statement. The DOC Statement also provides specific measurement standards for unit C-Level reporting (Department of the Air Force, 1992c:13).

Capability Level (C-Level)

A C-Level is a six point scale which measures the degree to which a unit meets the standards outlined in its DOC Statement (Department of the Air Force, 1992c:98). In general, C-Levels are calculated by dividing the number of available resources by the number authorized or required, and converting this percentage through a translation matrix to a corresponding C-Level (Department of the Air Force, 1987a:37). The C-Level matrices are located in Chapters Five and Six of Air Force Regulation (AFR) 55-15. Four measured resource areas summarize the unit's capability to support their wartime missions (Department of the Air Force, 1992c:23):

1. Personnel Measured Area. A measure of the availability of aircrew and direct support maintenance personnel.

2. Equipment and Supplies on Hand Measured Area. A measure of possessed aircraft and support equipment and

supplies. Possessed aircraft are the number of aircraft presently in operational use by a unit and are considered combat essential equipment. Support equipment and supplies status is a measure of a unit's ability to generate or deploy with resources specified in the DOC Statement (Department of the Air Force, 1987a:38).

The reported spares assessment package is an additional category of information included in this measured area's C-Level matrix. The percentage of sorties achieved measurement produced by the SAM is translated into the reported spares assessment package score in this matrix (Department of the Air Force, 1987a:36). This score reflects a unit's projected sustainability and combines with the possessed aircraft and support equipment measures to produce this area's C-Level (Department of the Air Force, 1987a:36). The utilization of WSMIS/SAM as an input source for this measurement area is specified in the unit's DOC Statement.

3. Equipment Condition Measured Area. A measure of the condition of a unit's fleet of aircraft with respect to the requirements of the unit DOC Statement. The DOC Statement provides a response time in which aircraft must be generated to a Mission Ready Available status. The DOC response time is a period in which aircraft are configured for their wartime missions. Configuration includes aircraft

servicing, weapons loading, and crew preflights (Department of the Air Force, 1987a:39).

4. Training Measured Areas. A comparison of the unit's current level of training with respect to a fully trained unit for war. The criteria for fully trained aircrews is dependent on the unit's tasking for the projected wartime mission specified in the DOC Statement. (Department of the Air Force, 1987a:40).

The overall C-Level measurements indicate the capability of a unit to provide prescribed levels of personnel, equipment, and training, necessary to achieve their DOC Statement mission. (Department of the Air Force, 1992c:84). All combat and combat support units report their weekly C-Level ratings through the SORTS reporting network. The SORTS report summarizes the single C-Level for each category and an overall C-Level that "reflects the proportion of its wartime mission(s) the unit is prepared to undertake" (Moore and others, 1991:13).

The overall C-Levels characterize the capabilities of the unit. The C-Level scores are presented in Table 2.2 (Moore and others, 1991:13).

Clearly, the desired and expected rating is C-1, which indicates that a unit is most likely to effectively perform its wartime mission (Moore and others, 1991:13). A C-Level less than C-1 attracts immediate attention throughout the command structure. The measured resource areas which

constitute the C-Level system contain the variable(s) that cause the substandard C-Level. These variables can be categorized as either personnel or equipment related, the same general factors presented earlier which limit the application of airpower (Stiles, 1993:27).

Table 2.2. Overall C-Level Rating and Corresponding Capability

C-Level	Description
C-1	Possesses required resources and is trained to undertake the *full* wartime mission for which it is organized or designed.
C-2	Possesses required resources and has accomplished training necessary to undertake the *bulk* of the wartime mission for which it is organized or designed.
C-3	Possesses required resources and has accomplished training necessary to undertake *major portions* of the wartime mission for which it is organized or designed.
C-4	Requires additional resources and/or training to undertake its wartime mission, but if the situation dictates, may be directed to undertake *portions* of its wartime mission with resources on hand.

Maximum Turn Rate Impact on C-Level

The C-Level measured resource area of interest with respect to maximum turn rates is the equipment and supplies on hand measure. The C-Level score of this measured resource area is dependent on the value of the reported spares assessment package (Department of the Air Force,

1987a:38). The reported spares assessment package value corresponds to the percentage of sorties achieved output generated by the SAM. Therefore, the specific SAM output which can produce an inaccurate C-Level is the percentage of sorties achieved. The C-Level score for the equipment and supplies on hand measured area and ultimately the overall C-Level may not reflect the true capability and sustainability status of a unit if the percentage of sorties achieved measurement is inaccurate.

Recall that the Dyna-METRIC model produces a performance report which estimates the probability of achieving the current day's sortie rate (Isaacson and others, 1988:27). This Dyna-METRIC model output appears in the SAM's capability assessment report as the percentage of sorties achieved measurement. In summary, the Dyna-METRIC model's estimated probability of achieving the daily sortie rate evolves into the SAM's percentage of sorties achieved measurement, which in turn influences the equipment and supplies on hand measured area and ultimately the accuracy of the overall C-Level.

The probability of achieving the daily sortie rate in the Dyna-METRIC model is dependent on the input parameters which define the combat scenario. One of these inputs is the maximum turn rate. The selection of an inflated or deficient maximum turn rate will introduce an unrealistic variable into the determination of daily sortie rate

attainment. The link between the maximum turn rate and a C-Level is not readily apparent, yet a distinct relationship emerges when the Dyna-METRIC model, the SAM, and the C-Level concepts are broken down and analyzed. The maximum turn rate enters this relationship through its application in the Dyna-METRIC model.

Maximum Turn Rate Application in the Dyna-METRIC Model

Equation 2.1 is the basic relationship within the Dyna-METRIC model which requires an accurate maximum turn rate (Isaacson and others, 1988:98):

$$(\underline{aM})(\underline{ST}) >= (\underline{A})(\underline{SR}) \qquad (2.1)$$

where

$\underline{aM}$ = minimum number of FMC aircraft that can achieve the requested sortie program (number of aircraft)

$\underline{ST}$ = maximum achievable sortie rate per aircraft or the maximum turn rate (sortie per aircraft)

$\underline{A}$ = number of assigned aircraft (number of aircraft)

$\underline{SR}$ = requested sortie rate per aircraft (sortie per aircraft)

As the maximum turn rate $\underline{ST}$ increases, the minimum number of FMC aircraft, $\underline{aM}$, required by the model to accomplish the requested sortie program will decrease. Recall that the Dyna-METRIC model will repeatedly fly

available FMC aircraft until the requested sortie program is accomplished. The Dyna-METRIC model will fly every requested sortie as long as the model recognizes even a single available FMC aircraft (Peterson, 1993). The maximum turn rate prevents this unrealistic situation from occurring.

By definition the maximum turn rate ST can never be smaller than the requested sortie rate per aircraft SR. An analyst cannot request more sorties than the maximum turn rate permits. When ST equals SR the number of assigned aircraft A is the minimum number of aircraft that can achieve the requested sortie program.

A realistic maximum turn rate exists between the significantly large and minimal values of ST. If the maximum turn rate ST is slightly larger than the requested number of sorties SR, the minimum number of required FMC aircraft aM will be slightly less than the number of assigned aircraft A. The requested sortie rate will be achieved if sufficient numbers of FMC aircraft are available. If insufficient numbers of FMC aircraft exist, the achievable sortie rate will be a percentage of the requested sortie program.

In summary, as the number of available FMC aircraft decreases, the number of sorties each aircraft must fly to achieve the scheduled sortie program increases. The FMC aircraft are rescheduled into the flying program to

compensate for sorties lost due to grounded NFMC aircraft. The limiting factor on expected number of sorties per FMC aircraft is the maximum turn rate (Isaacson and others, 1988:28). As shown previously, without a maximum turn rate all sorties could eventually be flown by a single FMC aircraft (Niklas, 1994). Therefore, the maximum turn rate represents a realistic operational constraint that has been incorporated into the Dyna-METRIC model to establish an upper limit on the number of sorties a single aircraft can fly each day.

Probability of Achieving Sorties

The Dyna-METRIC model determines the maximum number of a unit's aircraft which can be NFMC such that the remaining FMC aircraft can successfully accomplish the desired sortie program. This upper limit of NFMC aircraft is given by equation 2.2 (Isaacson and others, 1988:97):

$$\text{Maximum Number of NFMC Aircraft} = \underline{A} - \underline{aM} \quad (2.2)$$

where

$\underline{A}$ = number of assigned aircraft (number of aircraft)

$\underline{aM}$ = minimum number of FMC aircraft that can achieve the requested sortie program (number of aircraft)

In order to achieve the requested sortie program, no more than ($\underline{A}$ - $\underline{aM}$) aircraft can be NFMC (Isaacson and

others, 1988:97). The probability of achieving the desired sortie program is then the cumulative probability that ($\underline{A}$ - $\underline{aM}$) or less aircraft will be NFMC. A simple numerical example will clarify this concept. Note the importance of the maximum turn rate throughout this example. Let:

$$\text{maximum turn rate, } \underline{ST} = 3$$
$$\text{requested sortie rate, } \underline{SR} = 2$$
$$\text{assigned aircraft, } \underline{A} = 12$$

The minimum number of FMC aircraft that can achieve the requested sortie program ($\underline{aM}$) is calculated using equation 2.1:

$$\underline{aM} >= (\underline{A})(\underline{SR})/(\underline{ST})$$
$$\underline{aM} >= (12)(2)/(3)$$
$$\underline{aM} >= 8$$

The requested sortie program is provided by the product ($\underline{A}$)($\underline{SR}$) = 24. In order to accomplish the requested sortie program, at least eight FMC aircraft must be available for sorties. The maximum number of aircraft which can be NFMC is determined from equation 2.2:

$$\text{maximum number of NFMC aircraft} = \underline{A} - \underline{aM}$$
$$\text{maximum number of NFMC aircraft} = 12 - 8$$
$$\text{maximum number of NFMC aircraft} = 4$$

The probability of achieving the requested sorties is the cumulative probability that four aircraft or less will be NFMC (Isaacson and others, 1988:97). The requested sortie program cannot be completely accomplished if the number of NFMC aircraft is greater than four. Continuing this example, let the number of NFMC aircraft = 6. The number of available aircraft is now:

available aircraft = $\underline{A}$ - number of NFMC aircraft

available aircraft = 12 - 6

available aircraft = 6

The maximum turn rate ($\underline{ST}$) will limit the number of sorties the remaining available aircraft can perform. The total number of sorties which can be flown is:

total number of sorties = ($\underline{ST}$)(available aircraft)

total number of sorties = (3)(6)

total number of sorties = 18

The unit could not perform all of its tasked sorties once the number of NFMC aircraft passed the threshold of four aircraft. The Dyna-METRIC model calculates a daily probability distribution for the number of NFMC aircraft. The probability distribution of the NFMC aircraft specifies

the probability associated with each possible number of NFMC aircraft (Benson & McClave, 1991:196).

Using the numbers in the example above, the Dyna-METRIC model would determine the cumulative probability of four or less NFMC aircraft. This probability is the Dyna-METRIC model's probability of achieving the current days sortie rate.

Therefore, as the maximum turn rate increases, the minimum number of FMC aircraft required to fulfill the sortie program (aM) decreases (see equation 2.1). As aM decreases, the maximum number of NFMC aircraft required to prevent the complete accomplishment of the requested sortie program increases (see equation 2.2). Finally, as the maximum number of NFMC aircraft required to prevent the fulfillment of the requested sortie program increases, the cumulative probability of achieving the requested sortie program increases.

The delineation of maximum turn rate and the number of NFMC aircraft estimated by the Dyna-METRIC model is the key concept of this section. The Dyna-METRIC model generates the probability distributions for each possible number of NFMC aircraft at any time throughout the scenario. These distributions are unaffected by the maximum turn rate. The maximum turn rate functions as a limiting factor which establishes the maximum number of NFMC aircraft allowable for a required sortie program. The maximum turn rate sets

the level of NFMC aircraft and the Dyna-METRIC model calculates the cumulative probability of the number of aircraft which will not exceed that level of NFMC aircraft.

The majority of the information in the Dyna-METRIC performance report is derived directly from the probability distribution of the number of NFMC aircraft (Isaacson and others, 1988:93). An in-depth analysis of how these probability distributions are established is beyond the scope of this thesis. The interested reader is referred to "Dyna-METRIC Version 4, Modeling Worldwide Logistics Support of Aircraft Components" for a thorough discussion of the probability distributions (Isaacson and others, 1988:92-96).

Maximum Turn Rate Sensitivity Analysis

A sensitivity analysis of the relationship between maximum turn rate and projected 30 day daily sortie rates was recently performed by the Logistics Support Division at Air Force Material Command (AFMC) (Hass & Frabotta, 1994). The purpose of the sensitivity analysis was to investigate the effects of varying the maximum turn rate input to the Dyna-METRIC model, while holding the remaining input parameters constant for the given scenario.

The performance measures of interest were the SAM output summary statistics: percentage of sorties achieved, cumulative sortie percentages, and aircraft availability. The experiment was replicated with four different types of

aircraft. The specific aircraft analyzed in this experiment are not authorized for publication, but the general results of the analysis can be discussed (Hass & Frabotta, 1994).

Trends for each experiment revealed that as the maximum turn rate increased, the percentage of achievable sorties and cumulative sorties at day 30 increased. When maximum turn rates decreased, the percentage of achievable and cumulative sorties at day 30 decreased. The aircraft availability percentage in each experiment was not affected by the variation in the maximum turn rate (Hass & Frabotta, 1994). These results are consistent with the analysis presented in the prior section. In general, a larger maximum turn rate enables a single aircraft to perform a greater number of sorties in a 24-hour period.

It is important to note that rigorous statistical analysis of the data set was not performed and conclusive evidence as to the significance of maximum turn rates was not established. However, the general trends observed support the premise that maximum turn rates affect projected achievable sortie percentages estimated by the Dyna-METRIC model and the percentage of sorties achieved output produced by the SAM.

Maximum Turn Rate Selection

The analysis of the Dyna-METRIC model and WSMIS/SAM operating environments has shown that the selection of a

realistic maximum turn rate is an essential requirement for generating accurate projections of warfighting capability and sustainability. An inaccurate maximum turn rate has the potential to influence the C-Level scores reported in SORTS. The importance of the C-Level measurements is emphasized because all levels of the military command structure depend on SORTS for operational capability information.

The variables which define a realistic maximum turn rate were presented earlier in this chapter. The wartime scenario, manpower, and aircraft related variables which interact to formulate the maximum turn rates will be formally introduced in the next chapter. These variables are mentioned here to serve as a reminder of the factors which must be considered in the maximum turn rate selection process.

Current Selection Process. The maximum turn rates currently utilized in the WSMIS/SAM assessments are provided by the USAF Major Commands (MAJCOMs) (Hass & Frabotta, 1994). The Logistics Support Division at AFMC receives updated maximum turn rates at irregular intervals from the MAJCOMs. These maximum turn rates are generally selected on the basis of operations and logistics planners practical knowledge and personal experience (Pipp, 1994).

This process is severely flawed for two primary reasons. First, the selection criteria for the maximum turn rates are not standardized across the MAJCOMs (Pipp, 1994). The lack

of standardization has led to a situation where the WSMIS/SAM capability assessments may reflect varying degrees of accuracy. For example, designated Air Combat Command (ACC) and United States Air Forces Europe (USAFE) units operate similar versions of the F-15 fighter, yet two different maximum turn rates are provided by these commands for the WSMIS/SAM assessments (Hass & Frabotta, 1994). Combat-oriented decisions require consistent and accurate assessments of warfighting capability and sustainability. Neither consistency nor accuracy is guaranteed by the subjective and inconsistent policies currently employed in the maximum turn rate selection process.

The second problem is that the current MAJCOM policies establish a single maximum turn rate per aircraft type for application in all wartime scenarios. The dynamic wartime environment demands a flexible methodology for estimating maximum turn rates. The individual commands operate under regionalized conditions. Therefore, it is highly unlikely that a universal and static maximum turn rate will exist for a specific Mission Design Series (MDS) aircraft. A single maximum turn rate does not allow for changes in mission profiles or the availability of aircraft. The arbitrary selection of a single maximum turn rate for all scenarios prohibits the accurate assessment of a unit's combat capability.

War Mobilization Plan Five (WMP-5) Methodology. The WMP-5 provides wartime sortie and attrition data and contains maximum turn rates for each MDS aircraft (Department of the Air Force, 1992a:1-19). The maximum turn rates in the WMP-5 are theoretical values and are standardized for each type of aircraft (Peterson, 1993). These maximum turn rates have been calculated by a methodology developed by the Operations Plans Directorate at Air Staff (Bryant, 1993).

The methodology is based on the premise that an individual unit will accomplish a predetermined number of sorties for a given scenario. A daily flying schedule is programmed to meet the required sortie tasking. The maximum number of available aircraft at the start of the day is scheduled for missions. A percentage of the aircraft flown in the first wave of sorties is scheduled for a second mission. Subsequent missions follow a similar pattern until the required number of sorties have been achieved (Peterson, 1994).

This methodology accounts for expected aircraft component failures by scheduling only a percentage of aircraft for additional missions. Aircraft repairs are performed in the time between the aircraft's last sortie for the current day and the first sortie of the next day. The schedule is also adjusted as necessary to prevent aircrews from exceeding duty day and crew rest restrictions. A

specific number of aircraft is required at the start of the day in order to successfully accomplish the required sortie schedule under the conditions imposed by expected aircraft failures and aircrew restrictions. This specified number of aircraft is an input to an equation which calculates a planning factor called the Direct Support Objective (DSO).

Direct Support Objective (DSO). The DSO can be expressed in two ways. First, the DSO is the number of aircraft that a Readiness Spares Package (RSP) is designed to uphold (Department of the Air Force, 1992a:1-11). The DSO number is at least equal to a percentage of the total number of aircraft within a unit that are not missing a part due to supply shortfalls (Department of the Air Force, 1990:32). The second perspective is that the DSO is a percentage of the total RSP required for a full compliment of aircraft (Department of the Air Force, 1992a:1-11). The desired DSO percentages for each type of aircraft are published in the WMP-5.

Equation 2.3 represents the concept of the DSO and the basic DSO relationship (Department of the Air Force, 1990:32):

$$DSO = \underline{A}(\underline{DSO\%}) \qquad (2.3)$$

where

DSO = number of aircraft that the RSP is designed to uphold (number of aircraft)

$\underline{A}$ = number of available aircraft (number of aircraft)

$\underline{DSO\%}$ = percentage of available aircraft which must be supported by the RSP (percentage)

The $\underline{DSO\%}$ establishes the percentage at which supply is stocked in order to support the aircraft package. For example, let the number of available aircraft, $\underline{A}$ = 10 and the DSO percentage, $\underline{DSO\%}$ = 90%. Substituting these values into equation 2.3:

$$DSO = (\underline{A})(\underline{DSO\%})$$

$$DSO = (10)(.90)$$

$$DSO = 9 \text{ aircraft}$$

The RSP is designed to support nine aircraft. Another term for the DSO is the DSO goal (Department of the Air Force, 1990:32). The DSO goal for this example is to have enough spare parts in supply to support nine aircraft.

The DSO value is related to aircraft and sortie rates by the relationship in equation 2.4 below. (Hass & Frabotta, 1994).

$$DSO = \text{Maximum}\{[(\underline{A})(\underline{s})/(\underline{m})] + \underline{SA},\ \underline{DE}\} \qquad (2.4)$$

where

$\underline{A}$ = number of primary authorized aircraft for a specific unit (number of aircraft)

$\underline{s}$ = sortie planning factor, defined as the number of sorties per day an aircraft can be flown against. The sortie planning factor is included in the WMP-5 (sorties per aircraft per day)

$\underline{m}$ = maximum turn rate (sortie per aircraft)

$\underline{SA}$ = number of spare aircraft, any number of aircraft greater than that authorized for a specific unit (number of aircraft)

$\underline{DF}$ = DSO floor value, a minimum number of aircraft which must be supported by the RSP (number of aircraft)

The DSO is the maximum of the two terms in equation 2.4. The maximum turn rate in the WMP-5 is established by algebraic manipulation of equation 2.4. The DSO value established in equation 2.3 is substituted into equation 2.4. The number of authorized aircraft, sortie planning factor, number of spare aircraft, and DSO floor values are either previously determined or dictated by the scenario. The only unknown variable in equation 2.4 is the maximum turn rate $\underline{m}$.

An example will clarify the relationship presented in equation 2.4. Recall that the previously calculated DSO is nine aircraft and let:

number of authorized aircraft, $\underline{A}$ = 10

sortie planning factor, $\underline{s}$ = 2

number of spare aircraft, $\underline{SA} = 4$

Substituting these values into equation 2.4 and rearranging the equation produces:

$$DSO = [(\underline{A})(\underline{s})/(\underline{m})] + \underline{SA}$$

$$\underline{m} = (\underline{A})(\underline{s})/(DSO - \underline{SA})$$

$$\underline{m} = (10)(2)/(9 - 4)$$

$$\underline{m} = (20)/(5)$$

$$\underline{m} = 4 \text{ sortie per aircraft}$$

The maximum turn rates in the WMP-5 have been calculated using the methodology just described. The most current edition of the WMP-5, dated March 1993, has been published but not released for use (Hass & Frabotta, 1994). Thus, the maximum turn rates in the WMP-5 are not utilized in WSMIS/SAM assessments at this time.

This methodology is questionable because the DSO functions as the limiting factor on operations. Operations are constrained solely by a predetermined stockage level of spare parts in the RSP. The DSO methodology concedes that only a portion of a unit's aircraft will be capable of performing missions. The subsequent calculation produces a maximum turn rate which ensures that the requested sortie program is achieved. The accomplishment of a requested

sortie program should not be a stipulation in the selection of a maximum turn rate.

Two additional problems plague this methodology. First, the determination of a maximum turn rate in a dynamic wartime scenario cannot be readily produced by this method. Once a maximum turn rate is established, the methodology does not provide for variations in operations tempo, aircraft attrition, and aircrew availability. The second problem is that the methodology assigns a universal maximum turn rate to each MDS aircraft. As discussed previously, the variety of missions conducted by similar MDS aircraft, operating under unpredictable and evolving scenarios, is contrary to the theory that a single maximum turn rate applies for all military operations.

The general shortcoming of both maximum turn rate methodologies is that research and analysis confirming the accuracy of the SAM outputs based on these values has not been performed. These maximum turn rates may in fact provide sufficiently accurate SAM outputs. However, the literature review and forthcoming analysis of the variables affecting sortie generation indicate that these methods ignore fundamental relationships which define the human factors and physical aspects of the maximum turn rate concept.

The MAJCOM directed and WMP-5 methods presented above are not the only means to estimate maximum turn rates.

Several alternate methods for calculating maximum turn rates exist. These methods involve computer simulation and analytical techniques.

Logistics Composite Model (LCOM)

The LCOM system is a "large scale computer simulation used to model manpower and other logistical requirements" (Department of the Air Force, 1987b:2). The USAF employs the LCOM to simulate various scenarios, dependent upon different levels of authorized aircraft, flying missions, and sortie rates. The simulation results provide estimates of manpower requirements necessary to support a given scenario (Department of the Air Force, 1987b:5).

Francis Hoeber provides a more detailed explanation of the LCOM as:

> A Monte Carlo simulation that models the work centers that contribute directly to sortie generation. It accounts for the impact of resource quantities on the ability of an organization (airbase) to generate sortie-ready aircraft. (Hoeber, 1981:116)

The LCOM is an inherently large simulation, which typically models several hundred individual aircraft components for a single weapons system. To simplify the LCOM data base, the TAC TURNER model was developed (Hoeber, 1981:116).

TAC TURNER

TAC TURNER is an event simulation model of aircraft turnaround activities on a tactical airbase. The model determines:

> surge sortie generation capabilities for various tactical aircraft when constrained by airbase resources (e.g., maintenance, manpower, spare parts, POL, munitions, and aircrews). Turnaround functions include arming/dearming, battle damage repair, unscheduled maintenance repair, cannibalization, attrition, refueling, weapons loading, and WRM (war reserve material) resupply. (Hoeber, 1981:116)

The LCOM and TAC TURNER simulation models provide in-depth analyses of the logistics environment and accurately estimate logistic capabilities with respect to the anticipated operational scenarios. However, these models do not provide a complete assessment of the factors that affect a maximum turn rate. The actual sortie period and aircrew requirements are not addressed by the LCOM or TAC TURNER models. Another problem is that the LCOM and TAC TURNER models are computationally intensive, which prohibits their application as a flexible and timely methodology.

SORTIE Model

The SORTIE model is a special purpose macro model which derives estimates of maximum aircraft sortie rates (Jourdan, 1989:8). The inputs to the SORTIE model included data from

the South East Asia conflict, a 1978 B-52G surge test, normal peacetime operations, subsystem failure rates, technical order information on logistic procedures, and personal judgments. The model assumes that spare parts, Petroleum, Oil, and Lubricants (POL), and munitions supply do not inhibit operations (Jourdan, 1989:25).

The model accounts for five types of delays that occur between aircraft launches: scheduled mission time, aborted mission time, maintenance completion time, waiting period for next mission, and waiting period until night missions (Jourdan, 1989:25). The model for computing the aircraft sortie rate, based on these time consuming events, is given in equation 2.5 (Jourdan, 1989:25):

$$\text{Sortie Rate} = 24 \text{ Hrs}/(\text{Time per sortie}) \qquad (2.5)$$

where

Sortie Rate = the number of sorties a single aircraft can perform in a 24-hour period (sortie per aircraft per day)

Time per sortie = the summation of the time consuming events mentioned above (Hours per sortie)

A maximum turn rate is derived from the SORTIE model when the time per sortie value in equation 2.5 is minimized. As the time per sortie value decreases, the sortie rate

value on the left hand side of equation 2.5 increases. The sortie rate value represents a maximum turn rate. The literature review found only a report on this model, and an application and an analysis of the methodology was not presented. However, the SORTIE model accounts for manpower and aircraft limitations. The underlying logic of this method has been incorporated into our proposed methodology.

Stiles Crew Ratio Study

In his dissertation *Crew Ratio Implications for 24-Hour Warfighting*, Gerald Stiles defines aircraft turn rate time as "the average time required after a task to repair or otherwise ready a vehicle for reentry into the task flow process" (Stiles, 1993:44). The turn rate in the context of Stiles dissertation is the actual time an aircraft is undergoing pre- and postflight inspections, weapons loading, refueling, repairs, and scheduled maintenance.

Stiles calculated his turn rate by dividing the total NFMC time assessed against an A-10 unit during Operation Desert Storm by the number of sorties flown by that unit (Stiles, 1993:50). The resultant value was the average by-sortie, or task, "down time" or "turn time" for the A-10 (Stiles, 1993:50). While Stiles turn rate is not analogous to the maximum turn rate utilized in the Dyna-METRIC model, the computation of Stiles turn rate functions as a proposed

method to estimate the average time required to prepare an aircraft for its next sortie.

Expert System Study

An artificial intelligence expert system was developed in 1986 by Synergy, Inc. in order to examine sortie production factors under wartime situations (Synergy, 1986:1). The system represented the wartime scenario through user inputs and embedded designated default values (Synergy, 1986:30). One of these default values was turn rate. The system's turn rate is a planning factor which compensates for aircraft break and attrition rates (Synergy, 1986:33).

The methodology for calculating the system's turn rate is similar to the method developed by the Operations Plans Directorate for the WMP-5 methodology of calculating maximum turn rates. The system's turn rate methodology is based on four assumptions (Synergy, 1986:33):

1. All aircraft are available for the first launch of the day.

2. 80% of the aircraft which flew in the first series of missions will be available to fly a second mission.

3. 80% of the aircraft which flew in the second series of missions (64% of the original number) will be available for a third series of missions.

4. The daily flying scenario will be limited to three series of missions.

The assumed percentages take into consideration the probability of aircraft attrition, battle damage, and unscheduled maintenance which cannot be repaired in time for subsequent launches (Synergy, 1986:33). The total number of aircraft required to meet this flying schedule will represent the maximum number of sorties which can be flown in a day. This methodology does not calculate an optimal maximum turn rate because it intentionally grounds a percentage of aircraft after each series of missions. This conservative methodology also limits the daily flying scenario to three series of missions.

Maximum turn rates have been estimated through simulation and analytical methodologies. While these techniques demonstrate two research methodology options available for the analyst, several additional methodologies exist that potentially could resolve the problem of establishing aircraft maximum turn rates. An overview of these methodologies is in order at this point.

Simulation

According to Robert Shannon, simulation is:

> the process of designing a model of a real system and conducting experiments with this model for the

> purpose either of understanding the behavior of the system or of evaluating various strategies for the operation of the system. (Shannon, 1975:2)

The simulation methodology seeks to describe the system, construct theories that account for system behavior, and employ these theories to predict future behavior (Shannon, 1975:2). A simulation model provides an analysis of a system under specified conditions and can produce information about the system that is not available from known sources (Shannon, 1975:10).

Quantitative/Analytical Approach

The quantitative/analytical approach seeks to establish relationships between controllable inputs (decision alternatives) and outputs of interest (consequences) to the analyst. The determination of reasonably precise quantitative expressions for these relationships results in a model of the system. The resultant model predicts the consequences of the input decisions (Holloway, 1979:14). The model development consists of describing potential consequences and relating possible decision alternatives to these consequences (Holloway, 1979:26).

Linear Programming

Linear programming techniques can solve resource allocation problems which are subject to various

constraining conditions (Przemieniecki, 1990:7). Linear programming problems arise when simultaneous activities demand limited resources. A series of equations represent the allocation objective and associated constraints. The linear program determines how the resources are allocated in order to optimize the total effectiveness of the system (Przemieniecki, 1990:7).

Regression Analysis

Regression analysis is a methodology of estimating the relationship between the mean value of a dependent variable as it relates to an independent variable (Benson & McClave, 1991:456). A multiple regression model includes more than one independent variable. The steps involved in developing a multiple regression model are presented in the Benson & McClave text, *Statistics for Business and Economics*.

Decision Theory

Decision theory is a general description of a variety of statistical inference methods utilized when decisions are made under uncertainty (Przemieniecki, 1990:6). Uncertainty exists in a probabilistic decision environment. The probabilistic decision environment is characterized by a range of possible outcomes of decisions (Knowles, 1989:516). If the possible outcomes of a decision are known and can be assigned probabilities, then an optimal decision can be

determined that will maximize the effectiveness of the decision. The best way to present the decision options is to construct a decision tree, on which all possible decisions can be shown (Przemieniecki, 1990:6).

Methodology Summary

The different methodologies provide a list of problem solving tools and techniques. It is both necessary and desirable to fit the methodology to the problem rather than vice versa (Shannon, 1975:10). The lack of a validated methodology for establishing maximum turn rates is the problem this research will attempt to resolve.

Chapter Summary

This chapter has introduced the concept of maximum turn rates, defined the automated environment in which maximum turn rates are utilized, explained the significance of maximum turn rates with respect to unit capability assessments, analyzed methods and policies related to the establishment of maximum turn rates, and presented current methodologies for estimating maximum turn rates.

The theoretical relationships between maximum turn rates and relevant Dyna-METRIC model and SAM outputs were established. The effect of maximum turn rates upon the Dyna-METRIC model and the SAM outputs was tested and the positive results indicate the significance of maximum turn

rates within the Dyna-METRIC model and the SAM. Because the maximum turn rate is a variable input, methods of estimating the maximum turn rate were explored. The lack of a universally recognized method of estimating maximum turn rates has introduced inconsistency into the process of assessing unit capabilities. Unit capability assessments are reflected in C-Level scores and accompanying SORTS reports. Senior level military commanders utilize the assessments to determine operational strategies, employment decisions, and mission planning activities.

Overview of Chapter III

The next chapter will describe the research process for establishing the maximum aircraft turn rate methodology. In addition, the steps necessary to answer the research questions presented in Chapter I will be discussed.

III. Methodology

Introduction

This chapter documents the selection and application of the Quantitative/Analytical (QA) research methodology as a technique for developing the maximum turn rate methodology. The chapter reintroduces the Maximum Turn Rate Influence Chain from Chapter II and identifies the location in the influence chain where the research methodology will be applied. Following this review, the research questions from Chapter I are examined.

The selection of the QA research methodology is justified and a detailed description of this methodology and its application to this research are presented. The variables that influence the proposed maximum turn rate methodology are described. Next, the methodology for establishing maximum turn rates is introduced. Finally, a description of the experimental design and data analysis approach is presented.

The Maximum Turn Rate Influence Chain

The relationships between maximum turn rate, the Dyna-METRIC model, the SAM, SORTS reporting, and the readiness and sustainability assessments were explained in Chapter II. Several variables that influence maximum turn rates were alluded to but not explored in detail. This chapter will

specifically identify and explain the significance of these variables.

The dotted box in Figure 3.1 contains the components of the influence chain that are explained in this chapter. The methodology proposed will account for the relationships among the variables influencing maximum turn rates. Chapters IV and V will illustrate the impact the proposed maximum turn rate methodology has on the remainder of the influence chain.

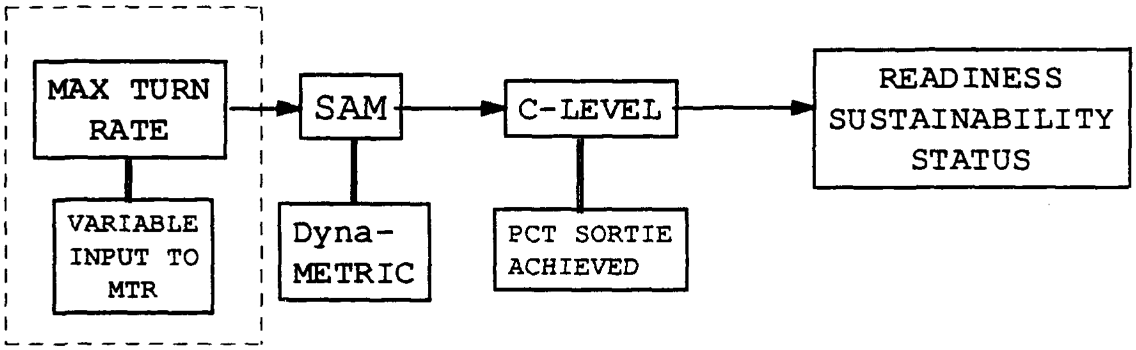


Figure 3.1. Maximum Turn Rate Influence Chain

Research Questions

In order to achieve the research objective of proposing a methodology for establishing maximum aircraft combat turn rates, all five research questions must be answered. A brief review of the questions will update the progress of the research to this point.

Research Question 1. What is the purpose of the maximum aircraft combat turn rate input to the Dyna-METRIC model? Maximum turn rate's definition and a thorough description of its utilization in the Dyna-METRIC model were presented in Chapter II.

Research Question 2. What is the relationship between maximum aircraft combat turn rates and unit capability assessments? A complete outline of how the maximum turn rate input influences the unit capability assessments generated by the SORTS reporting process and reflected in a unit's C-Level measurement was discussed in Chapter II.

Research Question 3. Does the maximum aircraft combat turn rate significantly influence unit capability assessments? As discussed in Chapter II, maximum turn rates influence the percentage of sorties achieved output produced by the SAM. This output affects the C-Level measurement of equipment and supplies on hand. If this measurement is erroneous, the overall C-Level of the unit could indicate that a unit does not possess the capability to perform its DOC Statement mission, when in fact it is capable of supporting its mission. Another possible outcome of an incorrect C-Level is an overly optimistic assessment of a unit's capabilities. In this case, the unit does not possess the capability to accomplish its DOC Statement mission. In either situation the information reported to senior level military commanders is inaccurate and may lead

to decisions that suboptimize the application of military forces. Once the proposed methodology is established, the specific impact the use of this methodology has upon the SAM output measures will be analyzed and presented in Chapter IV.

Research Questions 4 and 5. Research Questions 4 and 5 are answered in this chapter:

> 4. What operational characteristics that are not specific inputs to the capability assessment process affect the determination of maximum aircraft combat turn rates?
>
> 5. What methodology best establishes a valid and accurate maximum aircraft combat turn rate?

Research Methodology

Before selecting a research methodology, it is important to identify the parameters of the eventual maximum turn rate methodology. The parameters required by this thesis are: 1) The ability to select appropriate input variables for inclusion in the maximum turn rate methodology, 2) The flexibility to adjust the values of the input variables, 3) A robust methodology which is applicable for all MDS aircraft, 4) A relatively accommodating methodology which can be promptly utilized by the personnel who perform the SAM assessments, 5) An encompassing methodology which accounts for the critical factors involved with sortie

generation activities and mission performance, and 6) An accurate representation of the operational environment.

As described in Chapter II, computer simulation and analytic methodologies have been used to estimate aircraft maximum turn rates. Linear programming, regression analysis, and decision theory are additional methodology options. Of the methodologies reviewed, the most applicable to this research is a combination of the analytical and decision theory techniques known as the QA methodology. The QA methodology is the best technique for developing the maximum turn rate methodology because it provides the best overall fit for each parameter described in the previous paragraph.

Computer simulation enables an analyst to select variables, alter inputs, and accurately represent the operational scenario. However, computer simulation techniques are computationally intensive and the resultant cost in computer time and man-hours to perform simulations is prohibitive.

The development of a methodology based on regression analysis and linear programming techniques would only apply to the specific type of aircraft and scenario constraints upon which the models are established. These techniques provide virtually no flexibility or robustness and require data which would have to be produced by actually flying aircraft at their maximum capability. The literature review

found no instances in either wartime or exercise scenarios in which a unit actually flew at its maximum sortie rate. Therefore, the data required to build regression or linear program models is not available.

The most optimal mix of analysis techniques is the QA methodology. This methodology allows the analyst to select input variables, easily adjust input values, sufficiently represent multiple operational scenarios, and rapidly produce accurate maximum turn rates. Therefore, the best research methodology for this thesis is the QA methodology.

The QA Approach to decision making as outlined by Charles A. Holloway in *Decision Making Under Uncertainty Models and Choices,* is used as a model for investigating the variables influencing maximum turn rate. Figure 3.2 is a symbolic representation of this approach. This model,

> looks for relationships between inputs (or decision variables) over which managers have some control and outputs (or consequences) in which managers have an interest. It tries to establish reasonably precise quantitative expressions for these relationships. (Holloway, 1979:14)

The "reasonably precise quantitative expression" for establishing valid maximum turn rates is the methodology this research seeks to identify. Once the quantitative relationships among the variables influencing maximum turn rates have been established, a methodology can be proposed for establishing maximum turn rates.

Inputs, as shown in Figure 3.2, will be variables or alternatives that limit or enhance a unit's capability to fly sorties. There are two types of input variables: 1) Operational characteristics of the unit which are required inputs to the SAM, and 2) Variables that are not required as inputs to the SAM, yet influence the maximum turn rates. Research question 4 will be answered once these input variables are identified.

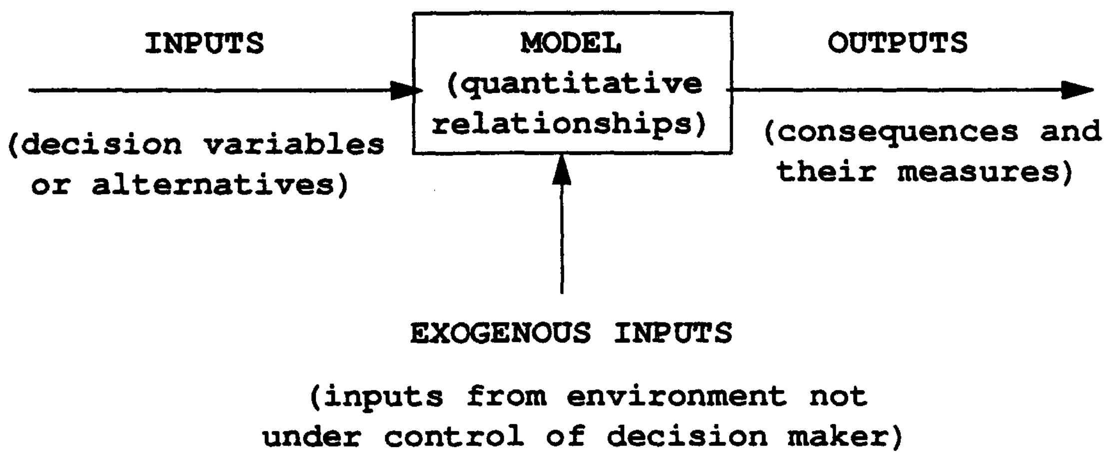


Figure 3.2. QA Methodology (Holloway, 1979:14)

Exogenous input variables are defined as those variables outside the control of the modeler or unit commander. Exogenous inputs will be based upon the external environment that affects a unit's ability to fly sorties. An example of this type of variable is the weather. Weather conditions

must be within tolerable limits in order to fly sorties but cannot be controlled by a unit.

The only output of interest in this model to the decision maker is a maximum turn rate which meets the criteria of the research objective. This maximum turn rate will ultimately influence capability assessments as alluded to in the Maximum Turn Rate Influence Chain, Figure 3.1.

The symbolic representation of the QA methodology applied to this research is pictured in Figure 3.3.

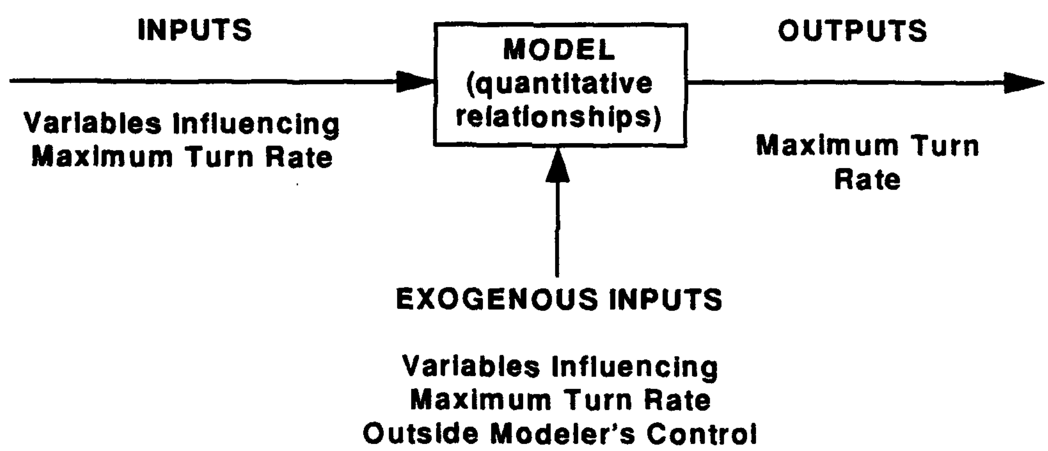


Figure 3.3. Maximum Turn Rate QA Methodology

Once the relationship between the input variables and maximum turn rate has been established, the methodology, for determining maximum turn rates will be proposed. This methodology will account for the established relationships and will provide a meaningful maximum turn rate input to the SAM.

Input Identification

Candidates for inclusion as input variables have been identified by investigating the tasks and resources required for an aircraft to fly a sortie. These variables have been identified from a "macro" point of view. This point of view allows for the identification of significant quantitative relationships between the maximum turn rate and its input variables without having to explore each task and resource in minute detail. The level of detail required to explore these variables from a "micro" point of view is beyond the scope of this thesis.

Therefore, where possible, variables that can be grouped together have been. An example is the time required to prepare an aircraft for a sortie. The aircraft must be fueled, armed, inspected, and taxied. These tasks are not identified individually but grouped together in the input variable labeled ground time.

Table 3.1 lists the different input variables identified that affect the maximum turn rate. The column labeled Type indicates where the variable fits in the QA methodology. The column labeled Source indicates where values for the variable can be found. For instance, the input variable Weather is exogenous and is thus a given condition. It is not calculated, found in regulations, or provided by the modeler or unit.

There are two basic resources required for an aircraft to fly a sortie: a fully mission capable (FMC) aircraft and a fully qualified pilot. As explained in Chapter II, the number of FMC aircraft is calculated by the Dyna-METRIC model. The Dyna-METRIC model forecasts the number of FMC aircraft by compiling and assessing the distribution of part failure rates and spare parts availability, unit repair and logistics pipeline capability, and cannibalization policy (Isaacson and others, 1988:88). The fully qualified crew requirement and additional variables are defined below.

Table 3.1. Input Variables for the QA Methodology

Input Variable	Type	Source
Runway	Exogenous	Given
Weather	Exogenous	Given
Aircraft	Exogenous	SAM
Sortie Duration (ASD)	Input	Scenario
Ground time (GT)	Input	MDS specific
Crew Ratio (CR)	Input	MDS specific
Crew Brief/Debrief (CBD)	Input	MDS specific
Crew Duty Day (CDD)	Input	MDS specific
Mission	Input	Scenario

Average Sortie Duration (ASD). Each scenario calls for an Average Sortie Duration (ASD) to be flown by each type of aircraft. The ASD is determined by the number of potential targets, geographical location of targets, type of aircraft, and type of munitions employed. The ASD is a controllable variable and the modeler may vary its value when different scenarios are assessed. However, the ASD is constant within a specific scenario assessment. The source of the ASD is the war plan or scenario modeled in the SAM.

Ground Time. The next input is the average Ground Time (GT). Ground Time is defined as the minimum time an aircraft must spend on the ground in preparation for its next sortie. This variable considers all ground functions aggregately. These functions include loading/unloading munitions, fueling, all taxiing, inspections, and other scheduled maintenance functions required to prepare the aircraft for the next sortie.

Crew Ratio (CR). The input variable Crew Ratio (CR) is defined as the number of fully qualified aircrews per aircraft in the unit being assessed. A fully qualified aircrew is defined as the combination of pilot, navigator, weapons controller, and/or other support personnel required to be aboard the aircraft in order to fly a sortie. For an F-16 an aircrew is one pilot; for a B-1 an aircrew is the combination of a pilot, a copilot, an electronic warfare officer and a weapons system controller.

Crew Duty Day (CDD). Crew Duty Day is an input variable limiting the number of sorties a crew can fly by restricting the number of hours in a day a crew member can be "on duty." Air Force Regulation 60-1(C1), 20 May 1991, defines a crew duty day as:

> A period that starts when an aircrew reports for a mission or briefing and ends when engines are stopped at the end of a mission or series of missions. (Department of the Air Force, 1991: 7-4)

The regulation states "In all aircraft, when only one pilot is aboard, a 12 hour maximum flight duty period applies" (Department of the Air Force, 1991: 7-8). Thus, restrictions on the number of hours a crew is available to fly sorties restrict the maximum number of sorties any given unit can fly over a period of time.

Crew Brief/Debrief (CBD). Crew Brief/Debrief (CBD) time is defined as the minimum time an aircrew must spend receiving a mission briefing and providing a sortie debriefing. The time a crew takes prior to a mission for essential mission planning, and the time a crew takes to debrief after a mission, utilizes hours of a crew duty day that would otherwise be available for a crew to fly sorties. This time is MDS specific and will vary according to mission requirements (Manyon, 1994). For the purposes of this research, the minimum wartime brief/debrief times are used as estimated by experienced HQ ACC/DOT crews. This time

constrains the number of sorties a crew can fly in a duty day, and therefore, limits the maximum number of sorties a given unit can fly over a designated time period.

Mission. The last input variable, Mission, covers several variables that are dictated by the characteristics of the scenario the unit is modeled against in the SAM. As outlined in Chapter II, the SAM models each unit against a specific war plan scenario. Though the characteristics of each scenario are controlled by the modeler, for the purpose of this thesis the mission scenarios are constant.

An example of a mission scenario input variable is number of aircraft at the start of the scenario. Each war plan calls for specific numbers, or packages, of aircraft. A European war plan may call for F-15s in a squadron size of 12. The required F-15 squadron size may be 18 in a Pacific theater war plan. The modeler has the ability to change this number. However, the resulting SAM outputs would be of little value, as the unit would not be accurately modeled against a current plan. Additional examples of scenario variables include unit cannibalization policy, RSP stockage levels, and logistics support capability.

Exogenous Inputs

Exogenous Inputs are defined as variables influencing maximum turn rates that are not controlled by the modeler.

There are three variables in this category: Weather, Runway, and Aircraft.

The weather must be within certain tolerances for aircraft to fly sorties. This input is considered to be outside of the control of the modeler. Weather is considered to be within tolerances for the purposes of this thesis.

An aircraft must have a suitable runway in order to fly sorties. SAM assumes a suitable runway is available for each scenario. This input is also considered given.

An aircraft is an essential requirement for flying a sortie. More specifically, the number of aircraft available on a given day to fly the planned sorties is required. The number of FMC aircraft is estimated by the SAM for each day in the scenario. The process the SAM uses to estimate this number was explained in Chapter II. For the purposes of this thesis, this input variable is considered given.

Outputs

The output for the QA methodology is the specific maximum turn rate established for input into the SAM. The quantitative relationships established through application of the QA methodology will provide the methodology required to establish valid maximum turn rates.

In Chapter II, the symbol for maximum turn rate was given as ST. ST is the symbol used for maximum turn rate in

the Dyna-METRIC model equations and relationships. To better facilitate the understanding of the following examples in this chapter, the maximum turn rate is given the symbol MTR (Maximum Turn Rate). The two terms can be used interchangeably.

Quantitative Relationships

As outlined in Chapters I and II, the maximum turn rate is defined as the maximum number of sorties an aircraft can fly in a 24-hour day. Any task requiring time that must be performed by or to an aircraft in order to fly sorties will consume portions of the 24 hours. For instance, if a sortie duration in a given scenario is 12 hours, considering only sortie duration, the maximum possible sorties for the aircraft in a 24 hour period is two. This example indicates a quantitative relationship between the maximum turn rate and the sortie duration and is presented in equation 3.1:

$$\underline{MTR} = 24 \text{ Hours}/\underline{ASD} \qquad (3.1)$$

where

$\underline{MTR}$ = maximum turn rate (sortie per aircraft)

$\underline{ASD}$ = average sortie duration (time per sortie per aircraft)

Substituting an $\underline{ASD}$ equal to 12 hours produces:

$$\underline{MTR} = 24 \text{ Hours}/12 \text{ hours}$$

$$\underline{MTR} = 2 \text{ sorties per aircraft}$$

If in this example we include the ground time (GT) input as defined above, the maximum possible sorties the aircraft can fly in 24 hours is some number less than two. For instance, a ground time of 1 hour per sortie translates to a maximum turn rate defined in equation 3.2 as:

$$\underline{MTR} = 24 \text{ hours}/(\underline{ASD} + \underline{GT}) \qquad (3.2)$$

where

$\underline{GT}$ = ground time per sortie (time per sortie per aircraft)

Substituting $\underline{GT}$ equal to one hour and $\underline{ASD}$ equal to 12 hours into equation 3.2 produces:

$$\underline{MTR} = 24 \text{ hours}/(12 + 1) \text{ hours}$$

$$\underline{MTR} = 1.85 \text{ sorties per aircraft}$$

This example establishes the first quantitative relationship between input variables and maximum turn rate. The relationship between the maximum turn rate and the input variables, average sortie duration (ASD) and ground time per sortie (GT), is defined by equation 3.3:

$$\underline{MTRg} = 24 \text{ hours}/(\underline{ASD} + \underline{GT}) \qquad (3.3)$$

where

$\underline{MTRg}$ = Maximum Turn Rate based on GT (sortie per aircraft)

$\underline{ASD}$ = Average Sortie Duration (hour per sortie per aircraft)

$\underline{GT}$ = Ground Time per Sortie (hour per sortie per aircraft)

An additional aircraft requirement for a sortie is an aircrew. This input will also impact the number of sorties an aircraft can fly in a 24 hour period. An aircrew duty day of 12 hours indicates that in a scenario calling for one aircraft and one crew, 12 of the 24 hours are available to fly sorties. Using the ASD (12 hr) from the previous example, it is clear that the maximum number of sorties this aircraft could fly is calculated in equation 3.4:

$$\underline{MTR} = \text{Available Crew Hours}/\underline{ASD} \qquad (3.4)$$

Substituting the values provided in the previous paragraph produces:

$$\underline{MTR} = 12 \text{ hours per crew}/12 \text{ hours per sortie}$$

$$\underline{MTR} = 1 \text{ sortie per aircraft}$$

This example can be expanded to account for the input variable labeled crew brief/debrief (CBD) time. The CBD time is added to the ASD and constitutes a portion of the aircrew's available duty period. Let the CBD equal one hour and rewrite equation 3.4 in the form of equation 3.5:

$$\underline{MTR} = \text{Available Crew Hours}/(\underline{ASD} + \underline{CBD}) \qquad (3.5)$$

where

$\underline{CBD}$ = Crew brief/debrief time (hour per sortie per aircraft)

Substituting the given values into equation 3.5:

$$\underline{MTR} = 12 \text{ hours per crew}/(12 + 1) \text{ hours}$$

$$\underline{MTR} = 0.92 \text{ sortie per aircraft}$$

This example can be expanded further to include more than one crew. The crew ratio (CR) is defined as the number of qualified aircrews per aircraft in a given unit. The above examples have been based on a scenario of one crew and one aircraft equaling a crew ratio of one. If the crew ratio is more than one, the number of crew hours available in 24 hours is greater than 12. For a crew ratio of 1.25, the crew hours available in 24 hours is 15 (1.25 x 12). Accounting for crew ratio, equation 3.5 becomes:

$$\underline{MTR} = (\underline{CR})[\text{Available Crew Hours}/(\underline{ASD} + \underline{CBD})] \qquad (3.6)$$

where

$\underline{CR}$ = crew ratio (number of aircrews per number of aircraft)

Substituting the values from equation 3.5 into equation 3.6, along with a crew ratio of 1.25 aircrews per aircraft, results in the maximum turn rate calculated in equation 3.7:

$$\underline{MTR} = (1.25 \text{ crews per aircraft})(12 \text{ hours}/13 \text{ hours}) \quad (3.7)$$
$$\underline{MTR} = 1.15 \text{ sorties per aircraft}$$

This example illustrates the second quantitative relationship between maximum turn rates and its input variables. This general quantitative relationship is expressed in equation 3.8:

$$\underline{MTRc} = (\underline{CR})[\underline{CDD}/(\underline{ASD} + \underline{CBD})] \quad (3.8)$$

where

$\underline{MTRc}$ = Maximum Turn Rate Based on Crew Ratio (sortie per aircraft)

$\underline{CR}$ = Crew Ratio (number of aircrew per number of aircraft)

$\underline{CDD}$ = Crew Duty Day (hour per day per aircrew)

$\underline{ASD}$ = Average Sortie Duration (hour per sortie per aircraft)

CBD = Crew Brief/Debrief (hour per sortie per aircraft)

The quantitative relationship between maximum turn rates and the input variables identified in Table 3.1 are illustrated in equations 3.3 and 3.8. The two exogenous inputs are considered given and outside of the control and scope of this thesis.

Maximum Turn Rate Methodology

Given that the maximum turn rate limits the number of sorties an aircraft can perform, a decision must be made between using the results of equation 3.3 (MTRg) or equation 3.8 (MTRc). The method for selecting which value to use is based on the values themselves. If the values from the two equations are equal, either may be input to the SAM. If the two values are not equal and the higher value is input to the SAM, the resulting capability assessment will be incorrect because the model would fly more sorties than physically possible.

In Chapter II an example was presented based on the relationship provided by equation 2.1. This example illustrates the relationship between MTRc and MTRg. As the maximum turn rate increases, the minimum number of FMC aircraft required to fulfill the sortie program decreases. As the minimum number of FMC aircraft required decreases,

the maximum number of NFMC aircraft required to prevent the complete accomplishment of the requested sortie program increases (see equation 2.2). Finally, as the maximum number of NFMC aircraft required to prevent fulfillment of the requested sortie program increases, the cumulative probability of achieving the requested sortie program increases.

This example illustrates that using the higher maximum turn rate results in artificially high sortie program achievement rates. While the maximum turn rate based on ground time (GT) may support one level of sortie program achievement, the maximum turn rate based on crew ratio (CR) may not be able to support the same level. The valid maximum turn rate will always be the smaller of MTRc or MTRg. This relationship represents the proposed maximum turn rate methodology. Equation 3.9 summarizes the methodology:

$$\underline{MTR} = \min(\underline{MTRg}, \underline{MTRc}) \qquad (3.9)$$

where

$\underline{MTR}$ = Maximum Turn Rate (sortie per aircraft)

$\underline{MTRg}$ = Maximum Turn Rate Ground time(sortie per aircraft) (from equation 3.3)

$\underline{MTRc}$ = Maximum Turn Rate Crew Ratio (sortie per aircraft) (from equation 3.8)

Experiment

This chapter has focused on the development of the methodology for establishing maximum turn rates. The culmination of selecting the QA research methodology, identifying model inputs, and defining the quantitative relationships has resulted in the proposed maximum turn rate methodology. In this section, an experimental test of the proposed methodology is introduced.

The experiment consists of several steps. First, the variable inputs identified in equations 3.3 and 3.8 are selected. These variables are defined by the operational characteristics of a typical scenario assessed by the SAM. This operational scenario is then modeled into the SAM. Based on the variable inputs, a maximum turn rate is calculated by employing the proposed methodology (see equation 3.9). This maximum turn rate is then utilized as an input to the operational scenario modeled in the SAM. A SAM assessment of the scenario is performed. Finally, the percentage of sorties achieved output generated by the SAM is recorded and analyzed. The Experiment Flow Chart depicted in Figure 3.4 outlines the flow of the experiment.

The structure of the experiment is developed through the performance of the following activities: 1) Select relevant variables, 2) Specify levels of treatment for these variables, 3) Control of the experimental environment,

4) Choose the experimental design, and 5) Data analysis (Emory and Cooper, 1991:419).

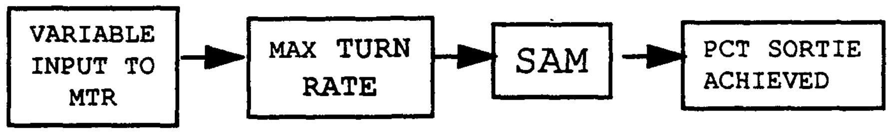


Figure 3.4. Experiment Flow Chart

<u>1. Select Relevant Variables</u>. The relevant variables for the experiment have been discussed in detail throughout this chapter. The independent variables that define the operational scenario modeled in the SAM are aircraft type and mission scenario. The average sortie duration (ASD), ground time, crew ratio, crew brief/debrief (CBD) time, and crew duty day (CDD) variables correspond to the scenario modeled in the SAM and represent the inputs to equations 3.3 and 3.8, which determine the maximum turn rate. The effect of varying the ground time and crew ratio variables with respect to the calculated maximum turn rates will be tested in this experiment.

The ground time is a relevant variable because this input is subject to fluctuations in a variety of factors. While the amount of time required to load weapons, refuel aircraft, and perform scheduled maintenance is relatively consistent, a specific value for these activities is only an

approximation. Therefore, the effect of varying ground time on maximum turn rate calculations will be tested.

The crew ratio is also subject to variations and thus, a definitive value for this input is not guaranteed. This input will fluctuate as the number of qualified aircrew members in a unit varies. The number of qualified aircrew members may vary due to noncurrent training qualifications, medical restrictions, and personnel assignments.

2. Specify Levels of Treatment for the Variables. Each independent variable has a level of treatment. The level of treatment is the distinction between different aspects of the treatment condition (Emory and Cooper, 1991:420). For example, ground time is hypothesized to have an effect on the maximum turn rate. The maximum turn rate then is hypothesized to influence the percentage of sorties achieved output utilized in C-Level measurements. The levels represent different values of the independent variable.

Two types of aircraft will be tested in this experiment. The type of aircraft is initially selected because the remaining variables are influenced by this selection. Note that the type of aircraft does not affect the maximum turn rate but is an essential requirement for the scenario modeled in the SAM. Different types of aircraft provide an increased opportunity for assessing the maximum turn rate methodology. The specific types of aircraft cannot be

disclosed due to the security classifications associated with the SAM assessments.

The type of aircraft and mission scenario establish the operational parameters within the SAM. The mission scenario defines the type of assessment performed in the SAM. Two types of scenarios can be modeled in the SAM: 1) a specific unit's DOC Statement mission profile and 2) the mission requirements for theater level operations. The primary difference between these scenarios is the composition of the designated RSP kits for each scenario (Hass & Frabotta, 1994). A unit level assessment is performed for one aircraft type, while a theater level assessment is conducted for the second type of aircraft. Testing both types of scenarios enhances the analysis of the maximum turn rate methodology.

The ASD input is dependent on the scenario modeled in the SAM. The scenario will dictate a required ASD necessary to accomplish the associated taskings. Thus, a single ASD for each scenario is utilized in determining the maximum turn rate. For the unit level tasking the ASD is 1.8 hours (Hass & Frabotta, 1994). The theater level tasking requires an ASD of 2.7 hours (Hass & Frabotta, 1994).

The CBD times are also subject to variations. However, in this experiment specific values will be incorporated into the maximum turn rate methodology in order to limit the number of treatment levels. Minimum values that represent

optimal CBD times are provided by HQ ACC/DOTW (Manyon, 1994). The unit and theater level assessments will utilize 1.5 and 2.0 hours respectively as the CBD times.

The CDD is described in AFR 60-1 as a 12 hour maximum flight duty period (Department of the Air Force, 1991:7-8). Therefore, a single treatment level for the CDD input applies for both assessments. The CDD is 12 hours for the experiment.

The treatment levels for the ground time input are based on the estimated "average" ground time for the specific aircraft. The estimated average is provided by the actual unit which is undergoing the SAM assessment. An approximate ten percent variation around the average ground time will account for anticipated variations experienced under actual operational conditions. The estimated ground time for the unit level assessment is 1.2 hours. The variation about this average includes values of 1.0, 1.1, 1.3, and 1.4 hours. The estimated ground time for the theater level assessment is 3.5 hours. The variation about this average produces values of 3.0 and 4.0 hours.

The crew ratio input will be tested over several levels as well. The standard crew ratio for a unit is reported in SORTS. The units receiving the SAM assessments provided the current crew ratios for the two scenarios involved in this experiment. The unit and theater level crew ratios are 1.28

and 1.17 respectively. Ten percent variations about these variables are provided in Tables 3.2 and 3.4.

Recall that the maximum turn rate is the minimum value represented in equation 3.9. The experiment will observe both possible cases. The first iteration will assume that the effects of the crew ratio produce a minimum maximum turn rate. The second iteration assumes that the ground time is the dominant factor in equation 3.9. Four experiments are conducted under this design. Tables 3.2, 3.3, 3.4, and 3.5 summarize the treatment levels for the independent variables utilized in determining the maximum turn rates.

Table 3.2. Treatment Levels for Unit Level Assessment, Maximum Turn Rate Based on Crew Ratio.

Crew Ratio	ASD	CBD	CDD	Maximum Turn Rate
1.15	1.8	1.5	12	4.1819
1.20	1.8	1.5	12	4.3637
1.25	1.8	1.5	12	4.5455
1.28	1.8	1.5	12	4.6550
1.30	1.8	1.5	12	4.7273
1.35	1.8	1.5	12	4.9091
1.40	1.8	1.5	12	5.0910

Table 3.3. Treatment Levels for Unit Level Assessment, Maximum Turn Rate Based on Ground Time.

Ground Time	ASD	Maximum Turn Rate
1.00	1.8	8.5714
1.10	1.8	8.2759
1.20	1.8	8.0000
1.30	1.8	7.7419
1.40	1.8	7.5000

Table 3.4. Treatment Levels for Theater Level Assessment, Maximum Turn Rate Based on Crew Ratio

Crew Ratio	ASD	CBD	CDD	Maximum Turn Rate
1.05	2.7	2.0	12	2.680
1.10	2.7	2.0	12	2.810
1.15	2.7	2.0	12	2.940
1.17	2.7	2.0	12	2.987
1.20	2.7	2.0	12	3.060
1.25	2.7	2.0	12	3.190
1.30	2.7	2.0	12	3.320

Table 3.5. Treatment Levels for Theater Level Assessment, Maximum Turn Rate Based on Ground Time

Ground Time	ASD	Maximum Turn Rate
3.00	2.7	4.210
3.50	2.7	3.870
4.00	2.7	3.580

3. Control of the Experimental Environment. An uncontrolled experimental environment can introduce extraneous variables into the experiment. These variables have the potential of distorting the measurements of the dependent variable (Emory and Cooper, 1991:421). Our experimental environment is confined to the WSMIS/SAM network. The WSMIS/SAM network ensures that extraneous variables do not influence the measurement of the percentage of sorties achieved. The output measures produced in the SAM assessment are dependent solely on the designated independent variables to the model.

The Dyna-METRIC algorithm ensures the controllability of the experiment because the Dyna-METRIC model is deterministic (Niklas, 1994). For a given set of inputs, the Dyna-METRIC model will generate one set of output data. All replications of the experiment will produce similar outputs. The only changes to the SAM outputs result from changes to the seven independent variables, which in turn

affect the maximum turn rate input to the Dyna-METRIC model. The deterministic characteristic of the Dyna-METRIC model enhances the control and validity of the experiment.

4. Choose the Experimental Design. The experimental design utilized in this experiment involves the comparison between two test cases. The purpose of the comparison is to observe the effects on the SAM assessments when the maximum turn rate input is varied. The maximum turn rate is the only input that is altered in the experiment. In this experiment case one is the actual SAM assessment currently performed for either the unit or theater. The current maximum turn rate provided by the MAJCOM is the maximum turn rate input to the SAM assessment. After the assessment is conducted, the percentage of sorties achieved is measured.

A new maximum turn rate is calculated by employing the proposed methodology. Maximum turn rates are determined from equations 3.3 and 3.8. The minimum of these maximum turn rates is then substituted into the identical assessment. The new assessment constitutes the second case portion of the experimental design. The percentage of sorties achieved is measured and comparisons with the case one values are conducted.

The strength of this design is its ability to control internal validity. Internal validity is a level of assurance that the conclusions drawn from a demonstrated experimental relationship actually imply cause (Emory and

Cooper, 1991:424). The nature of the Dyna-METRIC model, coupled with the experimental design, ensures that the cause of variation between the case one and case two measures of the percentage of sorties achieved is traceable to the different maximum turn rates utilized in the SAM assessment.

A weakness of this design is that external validity is not guaranteed. External validity is the degree to which the relationship observed can be generalized for other assessments (Emory and Cooper, 1991:424). The results of the experiment are not generalizable because of the scenario specific inputs to the SAM. The unique nature of the operational scenario, composition of the RSP kit, aircrew availability, and ground time capability prohibit a generalizable conclusion for other assessments. The results of the experiment will indicate whether the effect of the maximum turn rate is significant for the specific scenario under investigation.

5. Data Analysis. The SAM assessments project the capability of unit or theater level forces to sustain operations for 30 days. The 30 day goal reflects the length of time in which a unit's RSP kit is designed to provide spare aircraft parts. The SAM assessments produce output data for each day in the scenario. For example, the percentage of sorties achieved is reported everyday over the 30 day period. However, these daily measurements are not independent of one another.

Recall from Chapter II that the percentage of sorties achieved output is the probability of achieving the desired sortie program. This probability is a cumulative probability that the number of NFMC aircraft will not prevent the accomplishment of the scheduled sortie program (see equation 2.2). The Dyna-METRIC model forecasts when an aircraft will become NFMC by compiling and assessing the distribution of part failure rates and spare parts availability, unit repair and logistics pipeline capability, and cannibalization policy (Isaacson and others, 1988:88).

The key point is that the daily percentage of sorties achieved output is a cumulative measure over the 30 day assessment period. Therefore, the percentage of sorties achieved data is represented by a continuous probability distribution. The determination of the specific type of continuous probability distribution is the first step in selecting an appropriate approach to the data analysis.

The characteristics of the distribution will dictate which statistical tests can be performed on the data. A variety of comparative tests are available, provided the sample data sets represent approximately normal distributions and equal variances, and that the sampled data have been selected independently of each other (Benson and McClave, 1991:403).

The requirement for normality in this experiment is violated by the nature of the percentage sorties achieved

data. The relationship between the maximum turn rate and the percentage sorties achieved output was established in Chapter II. In short, as the maximum turn rate increases the percentage of sorties achieved will increase. Eventually, the maximum turn rate will surpass a threshold value and every programmed sortie will be achieved. The distribution of the percentage sorties achieved output will exhibit a linear rise and eventually a steady state value of one hundred percent.

Another factor to consider is that the 30 day assessment produces only a single data point. The cumulative probability of the percentage of sorties achieved cannot be partitioned into values measured on a daily basis. The experiment will generate a data point for each maximum turn rate input to the SAM assessment. These maximum turn rates correspond to a particular experiment as presented in Tables 3.2 through 3.5.

A test of hypothesis will produce an inference as to whether or not the percentage of sorties achieved output generated by the proposed maximum turn rate methodology is equal to the percentage of sorties achieved outputs currently produced by the MAJCOM directed maximum turn rates. The test of hypothesis employed must account for a small set of data, where the data exhibits nonnormal distribution characteristics. The test of hypothesis which meets these criteria is the one sample sign test.

The one sample sign test is a nonparametric procedure to test hypotheses about the central tendency of a nonnormal probability distribution (Benson and McClave, 1991:949). The objective is to determine whether the current percentage of sorties achieved represents an accurate median value. The null hypothesis is that the current methodology is correct and that approximately half of the subsequent samples of data will appear on each side of the hypothesized median (Benson and McClave, 1991:949).

The alternative hypothesis is that the central tendency of the sample data will either be greater or less than the percentage of sorties achieved produced by the current methodology. This two-tailed test assumes that the sample data is selected from a continuous probability distribution. The level of significance for this test will be 95 percent. This test of hypotheses shall be performed for the four experiments.

Chapter Summary

This chapter introduced the parameters in which the maximum turn rate methodology must conform. The rationale behind the selection of the Quantitative/Analytical decision methodology as the research technique was presented. The QA methodology provides the closest fit for the required parameters. The necessary inputs to the maximum turn rate methodology were justified. The proposed maximum turn rate

methodology was developed by integrating the QA technique with the identified inputs. An in-depth review of the experiment for testing the proposed methodology was provided. Finally, the test of hypothesis for establishing a statistical inference about the percentage of sorties achieved measurement was introduced.

Overview of Chapter IV

The experiments outlined above are performed on the four sets of inputs. The results of the experiments are presented, the one sample sign tests are performed, and the final results are analyzed.

IV. Data Description and Analysis

Introduction

Chapter IV documents the results of the experimental tests of the proposed maximum turn rate methodology, as described in Chapter III. The experiments previously outlined are conducted, the percentage of sorties achieved data is collected, and the one sample sign test is performed. The results of these experiments are analyzed and discussed.

Experiment Review

The experimental test of the proposed maximum turn rate methodology was explained in detail in Chapter III. A brief review of the experiment is provided for reference. SAM assessments of two operational units are performed. One of these units fulfills a theater level tasking, while the other supports a conventional unit tasking. Two different types of aircraft are operated by these units. Security classifications prohibit the disclosure of the specific units and the types of aircraft.

The SAM assessments performed on these units utilize maximum turn rates provided by the respective MAJCOMs. The results of these assessments reflect typical outputs currently utilized in determining unit C-Levels. These initial assessments function as baseline cases in the experiment.

The units involved in these assessments provided current information on unit crew ratios and approximate ground times. These values, along with scenario specific information, are input into the maximum turn rate methodology. The methodology generates new maximum turn rates that are based on realistic operational capabilities and scenario driven requirements. The new maximum turn rates are then input into the SAM and a second SAM assessment is performed.

Equation 3.9 requires that the minimum value of the maximum turn rates calculated in equations 3.3 and 3.8 be utilized as the input to the SAM assessment. For the purposes of this experiment, the effects of both the crew ratio based and ground time based maximum turn rates are tested for each scenario. Thus, four experiments are performed.

The output measure of interest in these experiments is the percentage of sorties achieved. This output is utilized directly in the calculation of a unit's C-Level. In case one only a single assessment is performed and it functions as the benchmark assessment. In the secondary portion of the experiment several assessments are conducted. Because the crew ratio and ground times are subject to fluctuations, a ten percent range of variation around the approximate crew ratios and ground times are tested. These varying inputs produce a range of maximum turn rates.

Experimental Results

The various treatment levels for the crew ratios and ground times were listed in Tables 3.2 through 3.5 in Chapter III. These tables provide the corresponding maximum turn rates for each treatment level. Similarly, the results of each experiment are summarized in tabular format. Tables 4.1 through 4.4 contain the relevant results of each experiment.

Experiment One. This experiment involves a unit level assessment where the maximum turn rate is based on the crew ratio. Table 4.1 summarizes the results of the experiment. The output measure of interest is the percentage of sorties achieved and is labeled PSA. The row labeled "Current Sam Inputs" is the unit's current SAM assessment value. The row labeled "Actual Crew Ratio" is the unit's crew ratio at the time of the SAM assessment. The calculations for the maximum turn rates in this experiment are provided in Exhibit 1 of the Appendix.

Figure 4.1 presents the results of this experiment graphically. The lowest percentage of sorties achieved value is produced by the current maximum turn rate.

Table 4.1. Unit Level Assessment, Maximum Turn Rate Based on Crew Ratio

Assessment Type	Crew Ratio	MTRc	PSA
Current SAM Inputs	N/A	3.5	98.30
Lower Boundary	1.15	4.1819	99.59
	1.20	4.3637	99.59
	1.25	4.5455	99.66
Actual Crew Ratio	1.28	4.655	99.66
	1.30	4.7273	99.69
	1.35	4.9091	99.69
Upper Boundary	1.40	5.091	99.69

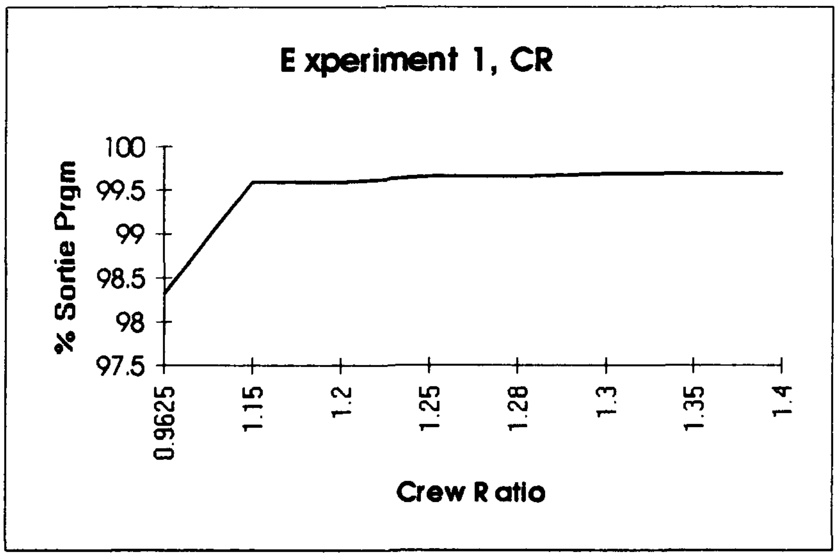


Figure 4.1. Percentage of Sorties Achieved Versus Crew Ratio for Unit Level Assessment

Experiment Two. This experiment involves a unit level assessment where the maximum turn rate is based on the ground time. Table 4.2 summarizes the results of the experiment. The row labeled "Current SAM Inputs" is the same input observed in experiment one. The row labeled "Actual Ground Time" is the current approximate ground time provided by the unit at the time of the SAM assessment. The calculations for the maximum turn rates in this experiment are provided in Exhibit 2 of the Appendix.

Table 4.2. Unit Level Assessment, Maximum Turn Rate Based on Ground Time

Assessment Type	Ground Time	MTRg	PSA
Current SAM Input	N/A	3.5	98.30
Lower Boundary	1.0	8.5714	99.83
	1.1	8.2759	99.83
Actual Ground Time	1.2	8.0	99.83
	1.3	7.7419	99.83
Upper Boundary	1.4	7.5	99.83

Experiments one and two are identical except for the values of the maximum turn rates. The maximum turn rate based on the ground time is higher than the maximum turn rate based on the crew ratio. The resultant percentage of

sorties achieved indicate that as the maximum turn rate increases, a greater number of sorties will be accomplished.

<u>Experiment Three</u>. This experiment involves a theater level assessment where the maximum turn rate is based on the crew ratio. Table 4.3 summarizes the results of the experiment. The row labeled "Current Sam Inputs" is the unit's current SAM assessment value. The row labeled "Actual Crew Ratio" is the unit's crew ratio at the time of the SAM assessment. The calculations for the maximum turn rates in this experiment are provided in Exhibit 3 of the Appendix.

Table 4.3. Theater Level Assessment, Maximum Turn Rate Based on Crew Ratio

Assessment Type	Crew Ratio	MTRc	PSA
Current SAM Input	N/A	2.0	98.14
Lower Boundary	1.05	2.68	98.90
	1.10	2.81	98.90
	1.15	2.94	98.93
Actual Crew Ratio	1.17	3.0	98.97
	1.20	3.06	98.97
	1.25	3.19	98.97
Upper Boundary	1.30	3.32	98.97

Figure 4.2 presents the results of this experiment graphically. The lowest percentage of sorties achieved value is produced by the current maximum turn rate.

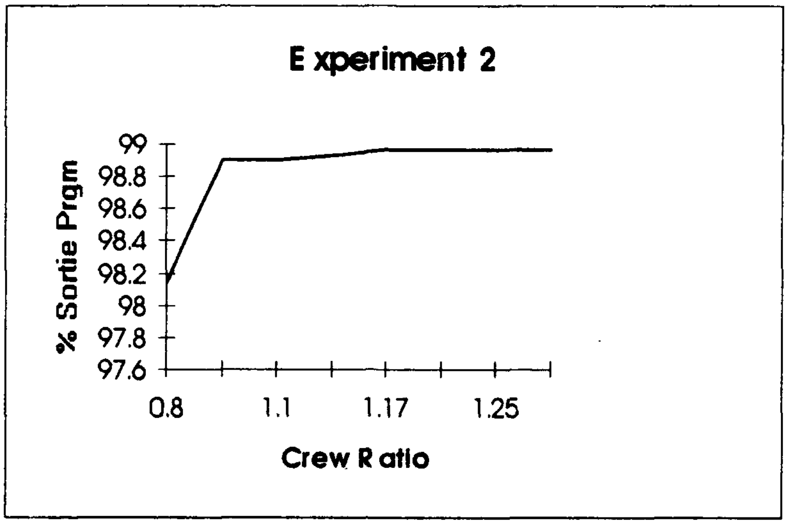


Figure 4.2. Percentage of Sorties Achieved Versus Crew Ratio for Theater Level Assessment

Experiment Four. This experiment involves a theater level assessment where the maximum turn rate is based on the ground time. Table 4.4 summarizes the results of the experiment. The row labeled "Current SAM Inputs" is the same input observed in experiment three. The row labeled "Actual Ground Time" is the current approximate ground time provided by the unit at the time of the SAM assessment. The calculations for the maximum turn rates in this experiment are provided in Exhibit 4 of the Appendix.

Table 4.4. Theater Level Assessment, Maximum Turn Rate Based on Ground Time

Assessment Type	Ground Time	MTRg	PSA
Lower Boundary	3.0	4.21	98.96
Actual Ground Time	3.5	3.87	98.96
Upper Boundary	4.0	3.58	98.96

Experiments three and four are identical except for the values of the maximum turn rates. The maximum turn rate based on the ground time is once again higher than the maximum turn rate based on the crew ratio. As observed in the first pair of experiments, the resultant percentage of sorties achieved indicates that as the maximum turn rate increases, a greater number of sorties will be accomplished.

Experiment Discussion

The results of these experiments indicate that for the two scenarios modeled in the SAM, the proposed methodology produces maximum turn rates that when input to the SAM, generate percentage of sorties achieved values that are minimally greater than the percentage of sorties achieved outputs realized by employing the existing maximum turn rates. Both the currently used maximum turn rates and the proposed maximum turn rates generate percentage of sorties achieved values that would correspond to a C-1 capability rating for the unit because at least 95 percent of the

sortie program is achieved (Department of the Air Force, 1987a:45).

Test of Hypotheses

The one sample sign test is employed to test the central tendencies of the nonnormal probability distributions. Figures 4.1 and 4.2 reaffirm the theory that the probability distributions of the percentage of sorties achieved data exhibit nonnormal characteristics. The sign test is utilized to test whether or not the percentage of sorties achieved outputs measured from the use of the current maximum turn rates in the SAM provide a centralized measure. A centralized output measure of the percentage of sorties achieved would function as an acceptable input to a unit's C-Level calculations.

The sign test is a relatively simple test of hypothesis. The test involves the statement of null and alternative hypotheses, measurement of a test statistic, establishment of an observed significance level, and the test for rejection of the null hypothesis. The assumptions associated with this test are that the sample data is selected randomly from a continuous probability distribution. Note that the shape of the probability distribution is irrelevant for this test (Benson & McClave, 1991:951).

Null and Alternative Hypotheses. The null hypothesis states that the percentage of sorties achieved outputs generated by the use of the current maximum turn rates represents the central tendency for all outputs. The alternative hypothesis states that a significant number of the percentage of sorties achieved outputs realized by the use of the maximum turn rates created by the proposed methodology will be either greater than or less than the current outputs. The hypotheses are presented below:

$$Ho: \underline{M} = \underline{Mo}$$

$$Ha: \underline{M} > \text{ or } < \underline{Mo}$$

where

Ho = the null hypothesis

Ha = the alternative hypothesis

$\underline{M}$ = the central tendency

$\underline{Mo}$ = the percentage of sorties achieved produced by the current SAM assessments

The values for each hypothesis test are included in Table 4.5. A sign test is performed for each of the four experiments conducted.

Test Statistic. The test statistic for this test is determined by counting the number of measurements that are greater than and less than the value of $\underline{Mo}$. The larger of

these two values is the test statistic. The test statistic is labeled $\underline{S}$ in Table 4.5.

The Level of Significance. The level of significance is designated by the p-value. This value is an observed binomial probability that a measurement will be greater than or equal to the hypothesized median value. The p-value is calculated by equation 4.1 below:

$$\text{p-value} = (2)\underline{P}(\underline{x} >= \underline{S}) \qquad (4.1)$$

where

$\underline{P}$ = the binomial probability

$\underline{x}$ = the number of observations greater than the test statistic

$\underline{S}$ = the test statistic

Binomial probability tables found in Benson and McClave's text, *Statistics for Business and Economics* provide the probability values for the variable $\underline{x}$ in equation 4.1

Rejection Region. This is the portion of the test where the decision is reached as to whether or not to reject the null hypothesis. If the observed p-value is less than the designated level of significance, the null hypothesis is rejected. The level of significance in this test is 0.05. Therefore, the results of the test can be assigned a confidence level of 95 percent.

Table 4.5 lists the results of the test of hypotheses. In order to reject the null hypothesis, the p-value must be less than or equal to the level of significance. The level of significance in this test is 0.05, which translates to a confidence level of 95 percent.

Table 4.5. Test of Hypothesis

Exp #	Null Hypothesis	Test Stat	p-value	Reject Null ?
1	M = 98.30	7	.016	Yes
2	M = 98.30	5	.062	No
3	M = 98.14	7	.016	Yes
4	M = 98.14	5	.062	No

Test Results

Experiments One and Three. Experiments one and three investigated unit and theater level assessments respectively. The maximum turn rates utilized in these experiments were based on crew ratios (see equation 3.8). The conclusion drawn from these experiments is that the sample of percentage of sorties achieved data provides sufficient evidence to reject the null hypothesis.

The implication of this conclusion is that the SAM assessments that are utilizing the current maximum turn rates are not producing the centralized value of the percentage of sorties achieved. The current SAM assessments, influenced by the maximum turn rate, yield

conservative percentage of sorties achieved values. The percentage of sorties achieved values that are incorporated into the unit's C-Level calculations do not represent the desired centralized values.

Although the percentage of sorties achieved values are less than the centralized values, the corresponding C-Level calculations for these experiments produce C-1 scores. The percentage of sorties achieved for cases one and two are significant enough to generate the C-1 scores. It is important to remember that, although in these experiments the C-Level ratings are the same, another experiment could yield dissimilar C-Level ratings. Each assessment is unique, and the results lack external validity. Therefore, the closer the percentage of sorties achieved value is to its centralized value, the more accurate the final C-Level rating.

Experiments Two and Four. Experiments two and four investigated unit and theater level assessments respectively. The maximum turn rates for these experiments were based on ground times (equation 3.3). In the test of hypothesis for these experiments, sufficient evidence does not exist at the 95 percent confidence level to reject the null hypothesis. However, if additional samples of percentage of sorties achieved data are collected, the test of hypothesis for experiments two and four would concur with experiments one and three.

The rationale for this theory is based on observations of the percentage of sorties achieved values found in Tables 4.2 and 4.4. The range of maximum turn rates in experiment two (see Table 4.2) extended from 7.5 to 8.5714 sorties per day. The percentage of sorties achieved value throughout this range was consistently 99.83 percent. Assessments produced with additional maximum turn rates within this range would also yield 99.83 percentage of sorties achieved values. The additional samples would increase the test statistic and lower the p-value. Once the p-value was less than 0.05 level of significance, sufficient evidence would lead to the rejection of the null hypothesis.

A similar argument exists for experiment four. Additional SAM assessments based on maximum turn rates within the ranges found in Table 4.4 would produce percentage of sorties achieved outputs of 98.96 percent. Additional samples would increase the test statistic and decrease the p-value. Once again the p-value would surpass the 0.05 level of significance, and sufficient evidence would suggest a rejection of the null hypothesis.

Methodology Results

The maximum turn rates generated by equations 3.3 and 3.8 should not be simultaneously employed. Equation 3.3 produces a maximum turn rate which is based on ground time, while crew ratios drive the maximum turn rates generated by

equation 3.8. The proposed maximum turn rate methodology presented in equation 3.9 requires the selection of the minimum of these two maximum turn rates.

Experiments one and two were based on the same unit level scenario. Thus, the maximum turn rates for these experiments are comparable. A proper application of the proposed methodology would only require an analysis of the data produced by experiment one. The results of experiment one therefore assume precedence over the results of experiment two.

Experiments three and four are comparable because they are based on a similar theater level scenario. Experiment three assumes precedence over experiment four according to the proposed methodology. The maximum turn rates calculated for experiment three are less than the maximum turn rates derived in experiment four.

Experiments one and three utilize maximum turn rates which are based on crew ratios. In both experiments the ability to fly sorties is limited by the availability of aircrews. The proposed methodology creates maximum turn rates that when input to the SAM, produce percentage of sorties achieved outputs that exhibit a central tendency. This central tendency of the percentage of sorties achieved output is greater than the percentage of sorties achieved output produced by current SAM assessments.

This difference between the central tendencies indicates that a percentage of sorties achieved value closer to the central tendency will provide a more accurate input to C-Level calculations. The proposed methodology creates maximum turn rates that when input into the SAM, result in assessments that produce more exact percentage of sorties achieved outputs. Subsequent C-Level calculations based on the percentage of sorties achieved more accurately reflect the unit's capability and sustainability.

Chapter Summary

This chapter presented the data and results of the experiments outlined in Chapter III. An analysis of the experimental data, a description of the test of hypotheses, and hypothesis test results were discussed in detail. Finally, a synopsis of the results of applying the proposed maximum turn rate methodology was presented.

Overview of Chapter V

Chapter V summarizes the conclusions concerned with the proposed methodology, presents recommendations associated with the methodology, and provides suggestions for further research.

V. Conclusions

Introduction

This chapter concentrates on three primary topics: 1) conclusions drawn from the research, 2) recommendations associated with the maximum turn rate methodology, and 3) suggestions for further research. After a brief reintroduction of the original objective, the problem solution is presented. This solution is the proposed maximum turn rate methodology. Next, the conclusions, recommendations, and suggestions for further research are discussed in detail. Included in the recommendations section is a description of an analysis flow chart designed for unit and theater commanders. This flow chart identifies operational variables which can indicate potential problems which would impact a capability assessment generated by the SAM.

Reintroduction of Problem

The objective of this thesis was to propose a methodology for establishing maximum turn rates. The current lack of a standardized method for establishing maximum turn rates adversely affects the SAM assessments of a unit's warfighting capability and sustainability. These unit characteristics are reported through the SORTS network and are measured in terms of a C-Level. The maximum turn rates presently used in SAM assessments are potentially

inaccurate because they have been randomly selected by the MAJCOMs. A standardized methodology for establishing maximum turn rates would eliminate the ambiguities that exist in the current maximum turn rate selection process.

The SAM assessments are utilized prominently in establishing the C-Level rating of a unit. The significance of an inaccurate unit C-Level must not be dismissed. The unit C-Level provides National Command Authorities, Joint Chiefs of Staff, and Unified and Specified commanders with a descriptive measure of the unit's capability to perform its assigned mission. The existing C-Levels of all units contribute towards force employment, combat strategy, and unit deployment decisions formulated by the highest levels of the military command structure.

Problem Resolution

In Chapter II, two problems with the current maximum turn rate selection process were identified. First, the selection criteria is not standardized across MAJCOMs. Each MAJCOM can choose different selection criteria for the same type units and aircraft. Second, current MAJCOM policies establish a single maximum turn rate per aircraft type for applications in all wartime scenarios. This single rate ignores the difference in unit capabilities (crew ratio and ground time) as well as differences in wartime scenarios (sortie duration). The proposed methodology standardizes the maximum turn rate selection process and accounts for

unique unit capabilities and the variety of wartime scenarios.

In the proposed methodology the characteristics of crew ratio and ground time are considered. Therefore, a unit's maximum turn rate is based on each individual unit's realistic capability to fly sorties. The term unit in the context of this discussion can refer to a specific wing, theater, or fleet of a specific aircraft type.

The characteristics of each scenario the unit is modeled against in the SAM are also considered. The primary benefit of this capability is that, instead of a generalized maximum turn rate input, a scenario specific maximum turn rate is utilized in the SAM assessment. This improved maximum turn rate is derived from the actual capabilities, limitations, and operational factors associated with the unit.

Sortie duration is another element of the maximum turn rate methodology. This variable defines the anticipated flying hours of the unit and is thus directly related to the SAM definition of maximum turn rate. The sortie duration can vary among scenarios and unit taskings. The proposed methodology accounts for these differences and incorporates the expected sortie duration into the maximum turn rate calculations.

In Chapter III, six parameters required for the maximum turn rate methodology were identified. The proposed methodology successfully accounts for each of the following parameters:

1. Appropriate input variables can be selected for inclusion in the methodology.

2. The methodology provides the flexibility to adjust the specific values of the input variables.

3. The methodology can be readily modified for all MDS aircraft. This robustness is critical in standardizing the maximum turn rate selection process. Another benefit is that as aircraft age, unit taskings change, RSP kits are modified, and manpower changes, the methodology will automatically adjust for these transformations.

4. The application of the methodology is straightforward and is relatively user-friendly for the personnel who perform the SAM assessments.

5. As previously discussed, the methodology accounts for the critical factors involved with sortie generation activities and mission performance.

6. The methodology realistically and accurately represents the operational environment.

The strength of the proposed methodology is its inherent ability to integrate the anticipated wartime scenario, specific manpower and aircraft related variables, and the factors required to successfully fly a mission into a cohesive process of determining the maximum turn rate. In addition, the methodology is encompassing, flexible, robust, and simple to apply. By synthesizing these characteristics and establishing logical relationships among the scenario,

manpower, and aircraft variables, a validated methodology for establishing maximum turn rates has been developed.

Conclusions

The intent of this research was to define the concept of maximum turn rate as it is utilized in unit capability assessments, accurately describe the requirement for a methodology for establishing maximum turn rates, and to logically develop this methodology. The following section summarizes these efforts and presents relevant conclusions.

Unit capability assessments cannot be successfully produced by the SAM unless a realistic maximum turn rate is included as an input to the SAM assessment. The purpose of our first two research questions was to define the maximum turn rate input as it is employed by the SAM and to establish the relationship between this input and the unit capability assessments generated by the SAM. By answering these basic questions, the requirement for the maximum turn rate as an input to the SAM assessments is substantiated.

The maximum turn rate methodology proposed in this thesis provides a universal method for determining maximum turn rates. A single methodology eliminates variations and disparities which currently exist in the MAJCOMs' methods of determining maximum turn rates. A standardized and Air Force approved methodology would ensure that the maximum turn rate input to the unit capability assessments performed by the SAM is consistently and accurately derived. The

resultant maximum turn rates would enhance the validity of comparisons among units, improve war planning capabilities, and increase the accuracy of capability and sustainability assessments.

This thesis has proved that unit capability assessments generated by the SAM are significantly influenced by the maximum turn rate. This relationship was detailed in Chapter II and affirmatively answered our third research question. The significance of this relationship appears in a unit's C-Level rating. The maximum turn rate influences the SAM output, percentage of sorties achieved. The percentage of sorties achieved value is utilized directly in calculating a unit's C-Level. The importance of the C-Level rating has been previously described.

Once again, a standardized methodology for establishing maximum turn rates would improve the validity of C-Level ratings throughout the Air Force. Incorporated in all C-Level calculations would be a common and consistent method for determining the maximum turn rate input utilized in the SAM capability assessments. Subsequent comparisons and analyses of unit capabilities would become more accurate because the inconsistencies which currently discredit the selection of maximum turn rates and potentially skew the unit's C-Level ratings would be eliminated.

The ultimate benefit of improving the accuracy of unit C-Level ratings is that the C-Level information required for command decisions becomes realistically representative of a

unit's capabilities. The commander's ability to formulate war plans, task units, implement combat strategy, and to initiate and sustain warfighting operations is enhanced by the improved accuracy of the reported C-Level ratings.

Recommendations

Methodology Flow Chart. Coincidental to the impact on unit capability assessments, this methodology provides unit commanders the ability to control the maximum turn rate and to thus influence their unit's C-level. Both the ground time (GT) and qualified crews per aircraft (CR) inputs in the maximum turn rate methodology can be controlled by the commander. Figure 5.1 illustrates the process the commander would follow by employing the proposed methodology to determine the appropriate maximum turn rate for the unit.

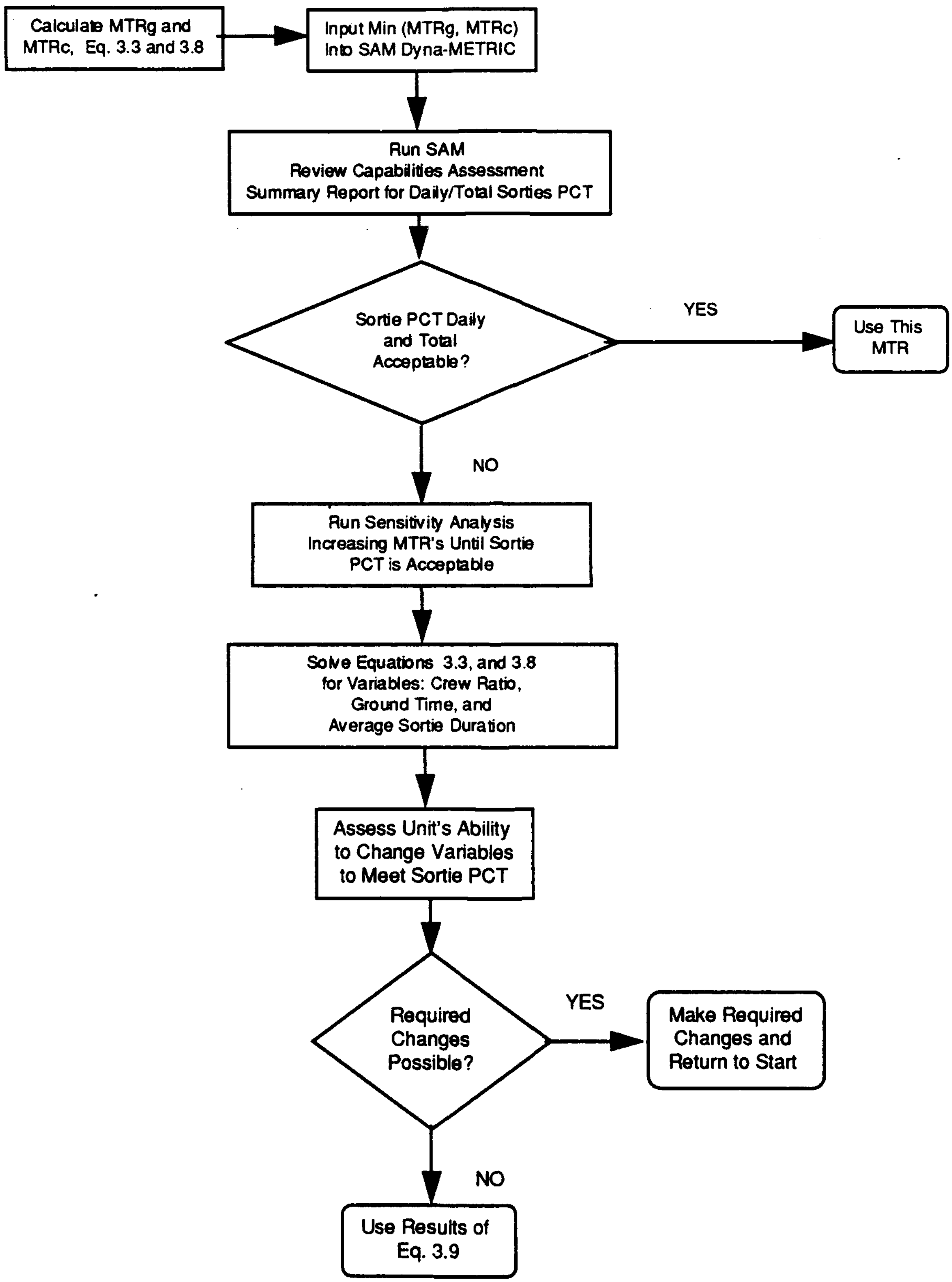
As outlined in Chapter II, the maximum turn rate input to the SAM is a limiting variable on the number of sorties achieved by a given unit. Maximum turn rate is used by the modeler to insure that not all programmed sorties are flown against one aircraft. An aircraft cannot fly more sorties in a 24-hour period than its maximum turn rate allows. The Maximum Turn Rate Decision Flow Chart depicted in Figure 5.1 outlines the process that a unit commander could follow to insure the proper maximum turn rate is input to the SAM for his unit. The flow chart identifies the crew ratio, ground time, and average sortie duration as variables that the unit

commander could concentrate on changing to improve his unit's maximum turn rate.

Crew Ratio. The crew ratio variable specifies the number of qualified aircrew members per available aircraft. A unit commander typically has little control over the number of aircrews authorized by the unit. The commander does, however, have control over the number of currently assigned aircrews that are fully mission qualified. By increasing the number of qualified aircrew members, the crew ratio variable will increase. Equation 3.8 shows that an increased crew ratio results in a higher maximum turn rate. This thesis has shown that a larger maximum turn rate translates into a greater percentage of sorties achieved output from the SAM and ultimately a higher unit C-Level.

Ground Time. The ground time variable encompasses all the activities necessary to recover, prepare, and launch an aircraft for its next sortie. According to equation 3.3, the reduction in ground time will result in a higher maximum turn rate. The ground time is primarily a logistics function within the control of the unit commander. Performing ground support activities, such as fueling, unloading and loading munitions, and inspecting the aircraft, will impact the ground time. Maintenance, supply, and transportation support for sortie generation significantly influence the ground time.

Maximum Turn Rate Decision Flow Chart
Figure 5.1



The average sortie duration input is beyond the control of the commander. Average sortie duration is specified in the unit's taskings and is dependent on the wartime scenario which the unit supports. However, a commander should realize the impact that the average sortie duration has upon the unit's maximum turn rate. The recent reduction in forces has resulted in fewer units. These units which previously could concentrate on a single mission may now be tasked to fulfill a variety of operations at any location in the world. Each tasking and area of operation would provide a unique average sortie duration. The capability to account for the average sortie duration would enhance the commander's ability to control and monitor the unit's maximum turn rate potential.

Suggestions for Further Research

Micro verses Macro View. As stated in Chapter III, this study has been accomplished from the "macro" viewpoint of which input variables are required to generate sorties. This view limited the depth of exploration of the input variables. The scope of the research necessary for this thesis limited the "micro" study of the input variables. Therefore, significant relationships may be discovered through a closer look at the input variables. The following three areas should be considered for further research:

1. The variable input Ground Time covers all tasks required to be performed on an aircraft in order to prepare

it to fly a sortie. What effect does the level of manpower or shortage of ground support personnel have on this variable?

2. The aspects of fighting a war can be anticipated to have an impact on the maximum turn rate calculations. For example, as a war progresses aircraft will be destroyed or lost, yet aircrews will be rescued or recovered. This will increase the ratio of crews per aircraft and thus introduce a fluctuating crew ratio input into the maximum turn rate calculation. Will attrition have a significant impact on maximum turn rates?

3. Currently, as stated in Chapter II, the maximum turn rate can be changed at any time in a 30-day war scenario assessment. For example, the first seven days of a wartime scenario is usually a surge period of flying sorties, and a specific maximum turn rate is utilized. An interim flying period, typically days 8-30, utilizes a different maximum turn rate. Both surge and interim periods are MDS and war plan specific. How often should maximum turn rates be changed throughout the SAM assessment? Should the maximum turn rate change daily, or should it remain constant throughout the assessment as changes in manpower and the effects of attrition combine to impact unit capabilities?

Further Testing. The maximum turn rate methodology should be tested on additional scenarios and upon all types of aircraft. The experiments in this thesis examined two such cases. Each SAM assessment is unique and the results

of an assessment are not generalizable. Therefore, additional experiments which involve a wider range of aircraft types and different scenarios are recommended. The "macro" view of the maximum turn rate concept allows for the application of the methodology to aircraft in strategic, reconnaissance, and airlift missions. Applying the methodology to other aircraft would increase the acceptance of the methodology and standardize the maximum turn rate inputs to the SAM assessments throughout the Air Force.

Summary

This thesis has established a foundation for further research concerning the topic of maximum turn rates. The essential concept of this research is that the maximum turn rate input into SAM assessments should accurately reflect the actual capabilities of a unit to generate and fly sorties. The use of the proposed methodology would insure that unit capabilities are the basis for SAM assessments. The improved accuracy of the SAM assessments would enhance the validity of unit C-Level ratings, thus enhancing the Air Force's ability to assess warfighting capabilities.

APPENDIX: Data Tables

Exhibit 1

CR: Crew Ratio
MTR: Maximum Turn Rate
AVG: Average Percent Sorties Achieved

CR	0.9625	1.15	1.2	1.25	1.28	1.3	1.35	1.4
MTR	3.5	4.1819	4.3637	4.5455	4.655	4.7273	4.9091	5.091
AVG	98.31034	99.58621	99.58621	99.65517	99.65517	99.68966	99.68966	99.68966
1	100	100	100	100	100	100	100	100
2	99	100	100	100	100	100	100	100
3	99	100	100	100	100	100	100	100
4	98	100	100	100	100	100	100	100
5	97	100	100	100	100	100	100	100
6	96	99	99	100	100	100	100	100
7	95	99	99	100	100	100	100	100
8	100	100	100	100	100	100	100	100
10	100	100	100	100	100	100	100	100
11	99	100	100	100	100	100	100	100
12	99	100	100	100	100	100	100	100
13	99	100	100	100	100	100	100	100
14	99	100	100	100	100	100	100	100
15	99	100	100	100	100	100	100	100
16	99	100	100	100	100	100	100	100
17	99	100	100	100	100	100	100	100
18	99	100	100	100	100	100	100	100
19	99	100	100	100	100	100	100	100
20	99	100	100	100	100	100	100	100
21	99	100	100	100	100	100	100	100
22	99	100	100	100	100	100	100	100
23	99	100	100	100	100	100	100	100
24	98	99	99	99	99	99	99	99
25	98	99	99	99	99	99	99	99
26	97	99	99	99	99	99	99	99
27	97	99	99	99	99	99	99	99
28	97	98	98	98	98	99	99	99
29	97	98	98	98	98	98	98	98
30	96	98	98	98	98	98	98	98

Exhibit 2

GT: Ground Time
MTR: Maximum Turn Rate
AVG: Average Percent Sorties Achieved

GT	0	1	1.1	1.2	1.3	1.4
MTR	3.5	8.5714	8.2759	8	7.7419	7.5
AVG	98.3103 4	99.8275 9	99.8275 9	99.8275 9	99.8275 9	99.8275 9
1	100	100	100	100	100	100
2	99	100	100	100	100	100
3	99	100	100	100	100	100
4	98	100	100	100	100	100
5	97	100	100	100	100	100
6	96	100	100	100	100	100
7	95	100	100	100	100	100
8	100	100	100	100	100	100
10	100	100	100	100	100	100
11	99	100	100	100	100	100
12	99	100	100	100	100	100
13	99	100	100	100	100	100
14	99	100	100	100	100	100
15	99	100	100	100	100	100
16	99	100	100	100	100	100
17	99	100	100	100	100	100
18	99	100	100	100	100	100
19	99	100	100	100	100	100
20	99	100	100	100	100	100
21	99	100	100	100	100	100
22	99	100	100	100	100	100
23	99	100	100	100	100	100
24	98	100	100	100	100	100
25	98	100	100	100	100	100
26	97	99	99	99	99	99
27	97	99	99	99	99	99
28	97	99	99	99	99	99
29	97	99	99	99	99	99
30	96	99	99	99	99	99

Exhibit 3

CR: Crew Ratio
MTR: Maximum Turn Rate
AVG: Average Percent Sorties Achieved

CR	0.8	1.05	1.1	1.15	1.17	1.2	1.25	1.3
MTR	2	2.68	2.81	2.94	3	3.06	3.19	3.32
AVG	98.13793	98.89655	98.89655	98.93103	98.96552	98.96552	98.96552	98.96552
1	99	99	99	99	99	99	99	99
2	99	99	99	99	99	99	99	99
3	99	99	99	99	99	99	99	99
4	99	99	99	99	99	99	99	99
5	99	99	99	99	99	99	99	99
6	99	99	99	99	99	99	99	99
7	99	99	99	99	99	99	99	99
8	99	99	99	99	99	99	99	99
10	99	99	99	99	99	99	99	99
11	99	99	99	99	99	99	99	99
12	99	99	99	99	99	99	99	99
13	99	99	99	99	99	99	99	99
14	99	99	99	99	99	99	99	99
15	99	99	99	99	99	99	99	99
16	99	99	99	99	99	99	99	99
17	99	99	99	99	99	99	99	99
18	99	99	99	99	99	99	99	99
19	99	99	99	99	99	99	99	99
20	99	99	99	99	99	99	99	99
21	99	99	99	99	99	99	99	99
22	98	99	99	99	99	99	99	99
23	98	99	99	99	99	99	99	99
24	98	99	99	99	99	99	99	99
25	97	99	99	99	99	99	99	99
26	97	99	99	99	99	99	99	99
27	96	99	99	99	99	99	99	99
28	96	99	99	99	99	99	99	99
29	95	98	98	99	99	99	99	99
30	91	97	97	97	98	98	98	98

Exhibit 4

GT: Ground Time
MTR: Maximum Turn Rate
AVG: Average Percent Sorties Achieved

GT	0	3	3.5	4
MTR	2	4.21	3.87	3.58
AVG	98.13793	98.96552	98.96552	98.96552
1	99	99	99	99
2	99	99	99	99
3	99	99	99	99
4	99	99	99	99
5	99	99	99	99
6	99	99	99	99
7	99	99	99	99
8	99	99	99	99
10	99	99	99	99
11	99	99	99	99
12	99	99	99	99
13	99	99	99	99
14	99	99	99	99
15	99	99	99	99
16	99	99	99	99
17	99	99	99	99
18	99	99	99	99
19	99	99	99	99
20	99	99	99	99
21	99	99	99	99
22	98	99	99	99
23	98	99	99	99
24	98	99	99	99
25	97	99	99	99
26	97	99	99	99
27	96	99	99	99
28	96	99	99	99
29	95	99	99	99
30	91	98	98	98

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1994	Master's Thesis

4. TITLE AND SUBTITLE

A METHODOLOGY FOR ESTABLISHING MAXIMUM AIRCRAFT COMBAT TURN RATES

5. FUNDING NUMBERS

6. AUTHOR(S)

James R. Dudley, Captain USAF
Michael J. Novotny, Captain USAF

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Air Force Institute of Technology,
WPAFB OH 45433-6583

8. PERFORMING ORGANIZATION REPORT NUMBER

AFIT/GLM/LA/94S-11

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

HQ USAF/LGSI
Washington DC 20330

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Air Force relies on the Status of Reports and Training System (SORTS) as an indicator of unit readiness. Unit Capability Levels (C-Levels) reported in SORTS are determined through measurements of on-hand resources and computer estimates of unit capabilities. Aircraft maximum turn rate, defined as the maximum number of sorties an aircraft can fly in a 24-hour period, is an input parameter to the assessment model. The methods used today produce maximum turn rates with unverifiable accuracy. Unit capabilities required to generate aircraft sorties are documented and their relationship to maximum turn rate established in this study. A unit capabilities based methodology for determining maximum turn rates is then proposed in this study. Results of the assessment model utilizing current maximum turn rates are compared to model results utilizing maximum turn rates calculated through the proposed methodology.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Air Logistics Support, Aircrews, Models, Logistics Planning, Logistics, Air Force Logistics Command	136
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL